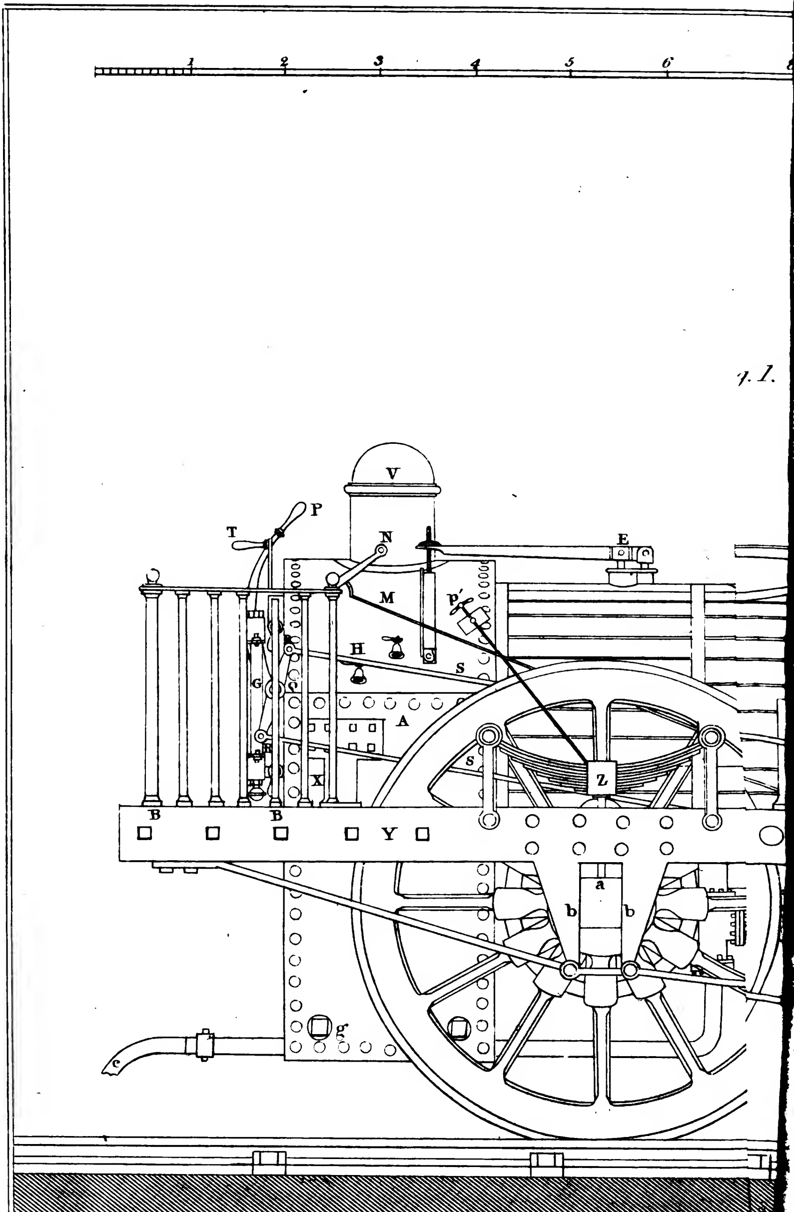

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A

PRACTICAL TREATISE

ON

LOCOMOTIVE ENGINES

UPON RAILWAYS;

A WORK INTENDED

To show the Construction, the Mode of Acting, and the Effect of those Engines in conveying heavy Loads; to give the Means of ascertaining, on an inspection of the Machine, the Velocity with which it will draw a given Load, and the Results it will produce under various Circumstances, and in different Localities; to determine the Quantity of Fuel and Water it will require; to fix the Proportions which ought to be adopted in the Construction of an Engine, to make it answer any intended Purpose; &c.

WITH

PRACTICAL TABLES,

GIVING AT ONCE THE RESULTS OF THE FORMULÆ;

FOUNDED UPON

A GREAT MANY NEW EXPERIMENTS,

Made on a large Scale, in a daily Practice on the Liverpool and Manchester Railway, with many different Engines, and considerable Trains of Carriages.

SECOND AMERICAN EDITION.

TO WHICH IS ADDED,

AN APPENDIX,

SHOWING THE EXPENSE OF CONVEYING GOODS, BY LOCOMOTIVE ENGINES, ON RAILROADS.

AND

A NEW THEORY OF THE STEAM ENGINE.

BY THE

François Guyonneau

CHEV. F. M. G. DE PAMBOUR,

FORMERLY A STUDENT OF THE ECOLE POLYTECHNIQUE, LATE OF THE ROYAL ARTILLERY, ON THE STAFF IN THE FRENCH SERVICE, KNIGHT OF THE ROYAL ORDER OF THE LEGION D'HONNEUR, ETC.

DURING A RESIDENCE IN ENGLAND FOR SCIENTIFIC PURPOSES.

Philadelphia:

CAREY & HART.

1840.

GRIGGS & CO., PRINTERS.

INTRODUCTION.

THERE exists no special work on Locomotive Engines. Two writers, Wood and Tredgold,* have indeed, in England, *slightly* touched upon that matter, but only in a subordinate manner, in treatises on railways; and, besides, they both wrote at a time when the art was scarcely beyond its birth. Consequently their ideas, their calculations, and even the experiments they describe, have hardly any relation to the facts which actually pass before our eyes, and can be of no use to such as wish to acquire a knowledge of these engines and their employ on railways.

Many questions had not even been entered into, others had been solved in a faulty manner. New researches on the subject became therefore indispensable. This work will, in consequence, be found completely different from any thing that has been published hitherto. No facts will be quoted, but such as result from actual observation; no experiments related, but those made by the author himself, on a new plan, and with new aims; finally, no theory exposed, but such as is derived from those experiments.

If at first sight it appear astonishing, that no theory of Locomotive Engines should exist, the surprise ceases on considering that the theory of the steam engine itself, taken in general, has not yet been explained. It was natural to

* "A Practical Treatise on Railroads, and Interior Communication in general, by Nicholas Wood." 1st edition, London, 1825; 2d edition, London, 1838.

"A Practical Treatise on Railroads and Carriages, by Thomas Tredgold." London, 1825.

suppose, that, respecting a machine at present in such universal use, and on a subject of such importance, every thing had been said, and every explanation given long ago. Far from this being the case, however, not even the mode of action of the steam in these engines has been elucidated. In the absence of such indispensable knowledge, all theoretical calculations were impossible. Suppositions were put in the place of facts. In consequence, we have seen very able mathematicians propose, on the motion of the piston in steam engines, analytical formulæ, which would certainly be exact, if all things went on in the engine as they suppose; but which not being founded on a true basis, fall naturally to the ground, in presence of facts. From this also results that, in practice, the proportions of the engines have only been determined by repeated trials, and that the art of constructing them has proceeded hitherto in the dark, and by imitation.

Locomotive Engines being first of all steam engines, we cannot advance in the researches we undertake, without solving at the same time the question relating to steam engines in general. There is even a remarkable point to be observed, which is, that of all sorts of steam engines, locomotive ones are those which in their application have to overcome the least complicated resistance, and the most susceptible of a rigorous appreciation. This circumstance renders them therefore more proper than any others, for furnishing an explanation of general facts common to all those machines. The theory once satisfactorily established in regard to Locomotive Engines, will, of course, apply equally to all sorts of steam engines, and more especially to those which like locomotive ones, work at a high pressure.

We flatter ourselves, therefore, that our researches, although apparently confined to Locomotive Engines, may at the same time illustrate the principal points of the theory of steam engines in general.

However, in order to indicate clearly the design of this

work, and to show in what it differs from those that have preceded it, we think proper to enter here into some particulars as to the points on which we have new researches to offer, either theoretical or experimental. It will be seen that those points embrace nearly the whole subject.

The pressure of the steam in the boiler, had been till now considered as invariable in every engine. It was calculated once for all, and by approximation, according to the weight on the valve. A great number of observations will show, however, how much it varies during the motion of the engine, and how necessary it is to take that circumstance into consideration, and to make use of a more exact mode of determination, lest the calculation should be entirely founded on an erroneous basis.

On that subject there will be found in our work, an alteration we propose making in the present disposition of the spring-balance, in order that it may show the true pressure; and also the description of a portable instrument we suggest for superseding the mercurial gauge, and which may be adapted to any engine.

The friction of the wagons was, until now, valued much too high. This error naturally rendered every calculation false, by misleading with regard to the true resistance overcome by the engines. A great number of experiments on wagons, with or without springs, alone or united in considerable trains, will show the real value of the friction.

The resistance of Locomotive Engines was still an unsolved question. We have endeavoured to determine it by three different processes, which may serve to verify each other.

The additional friction created in the engine by the load it draws, had never yet been submitted to any investigation. We shall present numerous experiments on that subject.

The exact determination of the pressure of the steam in the cylinder, was necessary to explain the mode of action of Locomotive Engines, as well as that of steam engines in

general, and to calculate the work they can perform in different circumstances. The erroneous ideas admitted in that respect, were the origin of all the faulty calculations, which experiment contradicted. We trust that the simple elucidation of that point will in a manner lay open the whole play of the engine.

The evaporating power of the engines was an element on which no experiment had yet been made, which was not even introduced in the calculations, and on which, however, definitively depends the effect these engines are able to produce. Experiments made on that subject, upon a great number of engines, will be found in this work.

An analytical equation, that might be adapted to solve the general problem of Locomotive Engines, was entirely wanting; that is to say, an equation by which might be known *a priori*, either the effects resulting from the given proportions of an engine, or, *vice versa*, the proportions that ought to be adopted, in order that predetermined effects in regard to load or speed may be obtained. The trials hitherto made to come to a solution of this question, being founded on a false principle, had produced formulæ in evident contradiction with facts. A rule had even been adopted, according to which the practical power of an engine was considered as equal to the third part only of its calculated or theoretical power; whereas, the whole applied power must evidently appear in the effect produced, and we shall see that it really does appear in it. This imaginary rule is a sufficient proof of the error of the calculations that were used, and could only lead to disappointments in practical applications. Engines were constructed, but the effect that they would produce was unknown. By the introduction of a new element of calculation, wrongly neglected until now, viz. the evaporating power of the engines, it will be seen that that question is solved in the most simple manner possible. From that equation, and simply by measures taken on the machine, the velocity and load of a Locomotive Engine may be imme-

diately found, and *vice versa*, the proportions which ought to be given to it, to make it answer any intended purpose. A great number of experiments, made in a daily practice, will show the accuracy of the formulæ. This is, at the same time, the theory of all high-pressure steam engines.

Several secondary dispositions of the mechanism of the engines had not yet been studied. It will, however, be seen that they are apt to deprive the machine of as much as a fourth part of its power. The effects of these dispositions, and in particular of that which is called the *lead of the slide*, will be submitted to calculation, and the results verified by special experiments.

The resistance proper to the curves of the railway deserved also to fix our attention. We shall endeavour to fix accurately the form of the wheels, and the disposition of the rails, by which that resistance may most effectually be remedied.

The consumption of fuel according to the load had not been determined in a satisfactory manner, and the rule proposed was contradicted by the experiment. This question will be established in a different manner, and the results confirmed by facts.

The researches on those points were made on twelve different engines, and numerous experiments were undertaken on each branch of the subject.

The method constantly followed consists in taking, first, the primary elements of the question from direct experiment; then making use of those elements to establish a calculation in conformity with theoretical principles; and, lastly, submitting the results to fresh and special experiments, in order to obtain their verification. For the farther elucidation of the formulæ, they are each time carefully submitted to particular applications, and, finally, to extend the use of the work to persons who may wish to find the results without calculations, each of these formulæ is followed by

practical tables, suitable to the cases which occur the most frequently in practice.

It does not enter into the plan we have traced ourselves, to give an elaborate description of the engine, nor the measures of its different parts, except those necessary for the researches we undertake. Such considerations would lead us too far, and concern more particularly works on construction. In like manner the figures added to our work, are only meant as illustrations of the text. They would be too imperfect for any other object.

The untrodden path in which we have been forced to enter, may have led us into some error. We by no means pretend to have produced a perfect work, and we claim indulgence for the mistakes which may have escaped us in so new a subject. Our chief aim was to be useful, while seeking a study congenial to our taste, and occupying the leisure of an inactive life. Early devoted to other pursuits, belonging to a family for several generations engaged in the military career, and the son of a General of Artillery, whose footsteps had naturally traced our direction, our studies would not have taken that turn, had we not been struck by the powerful effects of the moter we are going to describe, and by the important part it must necessarily act in modern civilization. We thought our work would at least have this result, to call the public attention on the subject. We shall feel happy if we have succeeded in some of our researches; and happy also if others, in correcting our errors, shall at least elucidate the facts upon which we have called their attention.

All the experiments related in the work were made by *ourselves*, with all the care and attention they required. Some were made in company with engineers of known talent and ability, as Mr. J. Loke, of the Grand-Junction Railway, and Mr. King, of the Liverpool Gas-Works. We give them in all their details, with a view that every one may judge of their accuracy; and we mention the place and

date of each experiment, in order to facilitate their verification by referring to the books, on which is registered the weight of each of the trains.

In regard to the facility we had of making these numerous experiments, we must say that, having applied to the heads of the most important undertakings of the sort in England, we were permitted, without restriction, to penetrate into the workshops, to take every measure, to collect all the documents concerning the expenses, and lastly, to make any experiment that appeared necessary to us.

It is with pleasure we acknowledge in the English character the liberality we have found in the whole course of our investigations.

To the friendship of Mr. Hardman Earle, one of the directors of the Liverpool and Manchester Railway, we owe in particular our warmest thanks. His obligingness never abated. Possessing all the qualities of an enlightened mind, he liked taking a part in researches which appeared to him conducive to the progress of science; and he permitted us to use all the engines and wagons of the railway. The beauty of these engines, their number, which is not less than thirty, the care with which they are kept, and the immense trade on that line, which gives the facility, without interfering with the business of the railway, to select loads for experiments as considerable and as light as one wishes, make that place the only one, perhaps, in the world, where experiments on a great scale may be made with the same precision as in general can only be obtained by a small apparatus. It is for that reason we preferred that railway to any other at present in activity, either in France or in England.

The same facilities were also offered us by the directors of the Darlington Railway. Interesting documents concerning the repairs and expenses of all sorts, incurred by that company, were obligingly communicated to us. We owe that obligation to the liberal authorisation of Mr. J. Pease

M. P., chairman of the company, and to the unremitting attentions of Mr. Robert B. Dockray.

We have studied the subject with all the interest, and, we might say, with all the enthusiasm it excited in us. In fact, what a subject for admiration is such a triumph of human intelligence! What an imposing sight is a Locomotive Engine, moving without effort, with a train of 40 or 50 loaded carriages, each weighing more than ten thousand pounds! What are henceforth the heaviest loads, with machines able to move such enormous weights? What are distances, with moters which daily travel 30 miles in an hour and a half? The ground disappears, in a manner, under your eyes; trees, houses, hills, are carried away from you with the rapidity of an arrow; and when you happen to cross another train travelling with the same velocity, it seems in one and the same moment to dawn, to approach, and to touch you; and scarcely have you seen it with dismay pass before your eyes, when already it is again become like a speck disappearing at the horizon.

On the other hand, how encouraging is the evident prosperity of those fine establishments. How satisfactory it is to acquire the proof that the Liverpool Railway produces 9 per cent. interest, and the Darlington one an equal profit! With what confidence must we not anticipate the future state of such undertakings, when we know that, besides the above-mentioned annual interest, the shares of the Liverpool Railway have risen, in four years,* from £100 to £210; and those of the Darlington Railway, in eight years, from £100 to £300? What may not society at large expect in future from this new industry, which will augment, tenfold, the capital and produce of the country, by the immense influence of speedy and economical conveyance!

* The first edition of this work appeared in French, in the beginning of 1835.

We shall in the course of the work make use of the following abbreviations:—

Ton - - - -	t.
Pound avoirdupois - - -	lb.
Foot - - - -	ft.
Square foot - - -	sq. ft.
Cubic foot - - - -	c. ft.
Inch - - - -	in.
Pound sterling - - -	£
Shilling - - - -	s.
Penny - - - -	d.

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A

PRACTICAL TREATISE

ON

LOCOMOTIVE ENGINES.

The plan we intend to follow in the course of this work will, we hope, render it both clear and methodical.

We shall begin by the description of a locomotive engine; and we shall acquaint the reader with the means by which the pressure of the steam may be accurately measured, so that, before we go any farther, he will be able to see the elements from which the power of the mover we are to employ is derived.

Our attention will afterwards be directed towards the resistances which that mover must overcome in its motion, so that we shall successively endeavour to discover as well the resistance of the wagons, as that which belongs to the engine itself, either when it moves alone, or when it draws a load after it.

These points first established, we shall pass to the general theory of the movement of locomotive engines, and we shall lay down the formulæ by which to determine, *a priori*, either the speed the engine will acquire with a given load, the load it will draw at a given speed, or the proportions which are to be adopted in its construction to make it answer any intended purpose.

After that, we shall have to consider several additional dispositions proper to the engine, which may exercise more

or less influence on the expected effect; and we shall then also treat of some external circumstances, the result of which may be of the same nature.

Lastly, we shall speak of the fulcrum of the motion, or of the force of adhesion of the wheel to the rails; and our last chapter will contain a calculation of the quantity of fuel required for the traction of given loads.

These inquiries will be sufficient to solve all the most important questions concerning the application of locomotive engines to the draft of loads.

They will sometimes be necessarily subdivided into several branches, and require calculation and theoretical illustrations, of more or less extent, though always plain and easy, and a series of experiments more or less numerous; but we shall take care to maintain, all along our work, the classification we at present lay down.

CHAPTER I.

DESCRIPTION OF A LOCOMOTIVE ENGINE.

ARTICLE I.

ENUMERATION AND DESCRIPTION OF THE PARTS.

Figure 1 represents a locomotive engine constructed on the most approved principle. Its mechanism is so simple, that a short description will be sufficient to explain its mode of acting. Whatever may appear unsatisfactory in this first sketch, will be cleared up by the particulars we shall have occasion to add in the course of the work.

The principal parts of the engine are: the fire-place and boiler, which constitute the means of raising the steam; the slides and cylinders which are the means of bringing into action the elastic force residing in that steam; and the cranks and wheels, by means of which the motion is transferred from the piston to the engine itself. When we have described those principal parts, we shall pass to some others of less importance, and then we shall fix the particular place each of those parts occupy in the engine.

SECTION 1.—*Of the Boiler.*

Figure 3 gives a complete idea of the boiler.

It shows the body of the machine, composed of three distinct compartments. The one to the right, or fronting the machine, and which is surmounted by the chimney C, is

separated from the two others by a partition *tt*. The two others together form the boiler. Both are filled with water to a certain height *cd*, but part of their internal space is occupied by the fire, as will be explained.

In the hindmost compartment is placed a square box, *e*, which contains the fuel, or forms the fire-place of the machine. Between the sides of that box, and those of the compartment in which it is contained, a space *qq* is left, which communicates freely with the remainder of the boiler, and which is consequently filled with water. The inner box is supported in the compartment in which it is contained, and joined to it by strong bolts, having the advantage of giving solidity to that part of the boiler which, not being rounded, offers less resistance than the cylindrical parts.

The fire-box, *e*, being thus placed in the middle of one of the compartments of the boiler, would be surrounded on all sides with water, were it not for the aperture *l*, which forms the door of the fire-place, and the bottom, *nn*, of the box which is occupied by a grate, one of the bars of which is represented at *nn*. This grate is more plainly seen in fig. 4, which represents the same fire-box seen in front.

Near the door *l*, and in the machine, is placed a strong supporting board, represented in fig. 1', by BB. The use of this board is for the engine-man to stand upon. Directly behind the machine comes the tender carriage for coke and water, so that it is easy for the fireman to throw coke in the fire by the door *l*, and to let water pass in the boiler whenever it may be necessary. This supply of water takes place by means of a forcing-pump put in motion by the engine itself, and of which we shall speak hereafter.

The lower part, *nn*, of the fire-place is occupied, as we have said, by a grate, and remains consequently open, admitting the external air required for the combustion of the fuel. The coke thrown into the fire-box, falls on the grate and is supported by it. When the fire is lit, and the door of the fire-box shut, the flame of the combustible remains confined in the fire-box. It would have no egress, if a num-

ber of small tubes or flues e' e'', the disposition of which is better seen in fig. 4, were not to lead the flame to the chimney, after passing through the whole length of the second compartment or cylindrical part of the boiler.

From that construction it will easily be conceived, that the fire being shut up in the fire-box, and completely surrounded with water, none of its calorific parts are lost. Afterwards, the flame, in its way to the chimney, divides itself among all the small flues we have mentioned. It crosses thus the water of the boiler, having a considerable surface in contact with it, and only escapes after having communicated to the water as much as possible of the caloric it contained. Once arrived at the extremity e'' of the tubes, the flame is in the compartment of the chimney, and escapes freely through the chimney C.

We see thus the heat applied here in two very distinct manners. All the water which surrounds the fire-box is in immediate contact with the fuel, and consequently subject to the action of the radiating caloric; on the contrary, the water which is placed in the middle compartment, receives its heat only from the contact of the flame and heated air which escape from the fire-box, so that it is exposed only to communicative heat.

It may be necessary to observe here, that the form of a boiler, with tubes, a form to which is undoubtedly owing the surprising power of the present locomotive engines, is a French invention. This ingenious idea belongs to M. Seguin, civil engineer and manufacturer in Annonay.*

* M. Seguin's patent bears the date of the 22d of Februrary, 1828; and it was not until April 25, 1829, that the commttee of directors of the Liverpool Railway called the attention of the English mechanicians towards locomotive engines, by proposing a prize on the subject. On October 6, of the same year; 1829, and not before, appeared the *Rocket* engine of Messrs. Stephenson and Booth, the principle and even the form of which differ in no way from M. Seguin's patent. We do not wish to detract from Mr. Booth's merit in having also conceived that happy idea. It is not the first time that two ingenious persons have had the same thought; but, by

Section 2.—*Of the Action of the Cylinders.*

The second important part of the engine is the apparatus of slides and cylinders. Fig. 3 is also designed to show the disposition of this part.

In the upper part of the boiler, that is to say, in the part occupied by the steam, there is a large tube VV', which is open at one of its ends and leads out of the boiler. It is by this tube that the steam is conducted into the cylinders. At V', in the interior of the tube, is a cock or regulator, the handle T of which extends out of the machine. By turning that handle more or less, the passage for the steam may be opened or shut at will.

The steam, being thus generated in great abundance in the boiler, and being unable to escape out of it, acquires a considerable degree of elastic force. If at that moment the cock V' is opened, the steam, penetrating into the tube by the aperture V, follows it to the entrance *v* of the valve-box. There a sliding valve *x*, which moves at the same time with the machine, opens a communication to the steam successively with each end of the cylinders. These are placed horizontally at the bottom of the chimney compartment, where the passage of the flame and the sides of that compartment protect them against the condensating effect of the cold air, and keep them in a proper degree of heat.

The direction of the arrows in the figure mark the line of

the above mentioned dates, it will be seen that the prior claim rests nevertheless with the French engineer.

The fact may be easily verified in England, by looking for a description of the patent in some of the following works, which are certainly to be found in the British Museum and other chief English libraries: *Annales de l'Industrie Française et Etrangère, ou Recueil Industriel et Manufacturier*, *année* 1828; *Bulletin de la Société d'Encouragement pour l'Industrie Nationale, année* 1828; *Description des Machines et Procédés consignés dans les Brevets d'Invention, de Perfectionnement et d'Importation, publiée d'après les Ordres du Ministre de l'Intérieur et du Commerce.* This last work we quote in advance, as it only gives the description of expired patents; M. Seguin's will not be mentioned until the year 1838.

circulation followed by the steam, from its entrance at the aperture V, into the slide-box. In the situation in which the slide is here represented, passage 1 is open to the steam, and consequently the piston is pushed in the direction of the arrow. At the following instant, passage 2 will be open in its turn, and the piston will be pushed in the contrary way. When the steam has produced its effect, it passes in the tube *v′*, and is conveyed by it to the chimney, through which it escapes into the atmosphere.

The introduction of the steam takes place at V, at a point purposely elevated, that the bubbling and jolting of the engine may not let the water of the boiler get in by the opening V.

Section 3.—*Of the Cranks and Wheels.*

The piston-rods being set in motion according to the foregoing explanation, and sliding in guides which prevent any deviation fron a rectilinear horizontal motion communicate a rotatory movement to the axle of the two hind wheels of the engine. This transformation of the alternate motion into a circular one, takes place after the manner of the common foot spinning-wheels, by means of a crank in the axle. This effect is clearly represented in fig. 3. There the steam may be seen forcing alternately the piston backwards and forwards and turning the crank *yz*, and at the same time the axle and the wheel which is fixed to it. However, as in the motion of a crank, there are two points in which the alternate force that puts the crank in motion, has no greater tendency to move it in one direction than in another, which takes place whenever the radius of the crank happens to be on the centre, that is to say, in the direction of the alternate motion; the two cranks respectively corresponding with the two pistons, are placed at right angles to each other. By that means one of the two has always its full effect whenever the other ceases to act, and the power of the engine never varies. The two cylinders being, as we have already said, placed beneath the boiler, the piston-rods communicate

directly under the engine with the above mentioned cranks, as appears in the figure. The crank-axle being set in motion, the wheels, which form one body with it, turn at the same time, and the engine is propelled in the same manner as a carriage which would be set a-going by turning the wheels round by the spokes.

The only fulcrum of the motion being in the adhesion of the wheels to the rails that support them, which adhesion causes them to advance instead of slipping round, it might appear doubtful whether, on such an even surface as the rails of a railroad, the engine could advance by means of the sole rotatory movement imparted to its wheels, particularly when the engine has to draw a considerable weight. But experience proves, that, however slight the adhesion of a wheel to a well-polished rail may appear to be, as, on the other hand, the power required to draw a load on a railroad is very small that adhesion is sufficient, and the engine progresses, followed by its whole train.

In ordinary cases, the adhesion of two wheels is sufficient; particularly with engines, the weight of which is distributed so that the drawing-wheels bear about the two-thirds of it. When a great power of adhesion is required, the four wheels are made equal. In that case one may, if necessary, connect the two wheels of the same side together, by metallic rods placed on the outside of the wheels. One of these connecting-rods is represented in fig. 6. C is the prolongation of the axle beyond the wheel. The crank arm C*o* is fastened to that prolongation of the axle, and must necessarily turn with it. The point *o* is a ball and socket joint; *m* is a cotton-wick syphon, by which the oil is fed in the joint; *nn* are keys designed to lengthen or shorten the rod, which at its opposite end is joined in the same manner to the crank-arm of the other wheel. The natural result of this is, that when the wheel or the axle C turns, it carries along with it the crank-arm C*o*, and thus communicates the same motion to the other extremity of the connecting-rod, and by it to the crank-arm of the second axle. Thus the power of the

engine is communicated by the two hind wheels to the two others, and the engine then adheres by its four wheels.

In order that, while in motion, the engine may not slip off the rail, which, we know, are iron bars projecting above the ground, the wheels have, on the inner side, a flange that prevents any lateral motion. But as, on the other hand, that flange ought not to be in danger of constantly rubbing against the side of the rail, the tire of the wheel is not exexactly cylindrical, but slightly conical. Its diameter is a little larger on the side of the flange than on the outward side; the consequence of which is, that, supposing the engine were to be for a moment pushed to the left, the left wheel resting on its broadest part, would pass over more way than the right wheel, and by that means bring the engine back to its true place between the rails. Wheels of such a form may be seen in fig. 2.

Section 4.—*Of the Safety Valves.*

The three preceding points form the foundation on which the action of the engine rests; the other parts are only secondary ones, that is to say, only designed to make the power produced by the former ones efficient. The boiler has two safety-valves E, F (fig. 1,) one of which is sometimes shut up in a box, to put it out of the reach of the engine-man, and to prevent him from overcharging it, as he might be tempted to do in order to obtain from the engine a greater effect, even at the risk of damaging it. More commonly, however, that precaution is given up, on account of its inconvenience.

Section 5.—*Of the Water Gauge.*

A gauge is likewise fixed to the machine to show at what height the water stands in the boiler. This gauge is a glass tube *mn* (fig. 7,) inchased at both its ends in two verrals *aa*, with cocks communicating with the interior of the

boiler and appearing outside, as may be seen in the figure. When the two cocks *rr* at top and bottom of the tube are opened, the water penetrates into the tube and takes the same level as in the interior. The cock S is designed to let that water afterwards run off. The use of this instrument is, that the engine-man may know when it becomes necessary to let the apparatus be refilled from the tender. As, however, the tubes and other parts of the boiler begin to suffer, that is to say, are apt to crack, when the water gets too low in the machine, there are, for more safety, on the side of the boiler, two and sometimes three small cocks, placed at different heights; by opening which, one after the other, the level of the water in the interior may be still more positively ascertained. If it be necessary to know at what height the water stands in the boiler, it is not less so to be certain of the real degree of elastic force the steam possesses; for, should that force not be sufficient, the engine would be unable to accomplish its task: but as this point requires to be explained at some length, we shall at a farther period make it the subject of a chapter by itself.

Section 6.—*Of the Slides.*

We have another important object to clear up. We have said above, that the slide-valve admits successively the steam above and below the piston of each cylinder, the result of which is the alternate motion, source of the final progressive motion of the engine. The engine-man then having opened the regulator or cock that admits the steam into the pipes, the steam proceeds from the boiler through the tube *v* (fig. 8) to the valve-box, and, pressing with all its force on the upper part *x* of the sliding-valve, compels it to remain in immediate contact with the plane in which it slides, while performing its motion. When the slide is in the situation in which it is represented in the figure, the steam takes the way marked 1, acts upon the piston, and pushes it in the direction of the arrow. In the mean while, the steam under

the piston escapes through the passage 2, which then communicates with the exterior, by means of the aperture *e*. When this first effect has been produced, the slide, by means of its rod *l*, is pushed in the position marked by the dotted lines. Then, on the contrary, it is the passage 2 which is open to the steam coming from the boiler: it pushes, consequently the piston in the opposite direction to its first motion; while the passage 1, communicating in its turn with the aperture *e*, gives free egress to the steam that has produced its effect. The alternate motion continues thus: the slide passing from one position to the other, by which it opens and shuts successively the passages, so that the steam may act alternately above and below the piston. The steam is afterwards led to the chimney, as will be explained hereafter, there to augment the current of air by which it causes the draft of the fire.

The motion of the slide is regulated so as to accompany the motion of the piston, but still to precede it by a very short instant: that is to say, that instead of opening the proper passage for the stroke of the piston just at the moment the piston is going to begin that stroke, it opens it a little beforehand. This is called giving a little *lead* to the slide. By that means, at the moment the piston begins its motion, the steam has already its full action upon it. We shall have occasion to come back to this point, when we shall see that this disposition, which is favourable to the speed of the engine, can be advantageously employed only within certain limits, beyond which it would be prejudicial to the load the engine is able to draw.

Section 7.—*Of the Eccentric Motion.*

The alternate motion of the slide is performed by the steam itself. To comprehend this point requires some attention.

An eccentric wheel is fastened to the axle, and, as this

turns, the eccentric, drawn along by its motion, pushes and draws alternately the rod of the slide.

This effect is represented in figs. 9 and 10. The point O is the centre of the axle, of which the section appears hatched. The point *m* is the centre of the eccentric, hatched in a contrary direction. The axle, in turning, draws the eccentric along with it, and makes, consequently, the point *m* describe a circle round the point O. In that motion the point *m*, passing successively to the right and to the left of the centre O, must necessarily, by means of the ring *nn*, which encircles the eccentric, push and draw alternately the shaft L, which acts upon the slide.

On the other hand, the point C representing the extremity or throw of the crank of the axle, which is set in motion by the piston, it will appear that when the steam-pushing the piston from one end of the cylinder to the other, makes the crank revolve half way round, the axle makes also the half of a revolution round itself; so that the point *m* describes the half of a circumference round the point O, and consequently the eccentric pushes the shaft L, and by it the slide-rod *l*, from one of their extreme positions to the other.

Thus placed, by this first operation, the slide now admits the steam on the opposite side of the piston. The piston then goes back, makes the axle revolve again half way round, whereby the slide is brought back to its original position, which suits the next stroke of the piston; and so forth.

The effect of drawing and pushing alternately the slide-rod by means of the rotation of the eccentric, is accomplished by means of a metallic ring *nn* fixed at the end of the shaft L, and in which the eccentric-wheel turns, the surfaces which are in contact being smooth and lubricated with oil. By this arrangement, while the great radius of the eccentric passes in turning from one side of the centre to the other, it carries along with it the shaft fastened to the ring, and communicates to that shaft the alternate motion.

By this it will be seen that the eccentric wheel acts here the part of a common crank, for transforming the circular

motion of the axle in an alternate motion applied to the slide, on the contrary principle to that which changes the alternate motion of the piston into a circular motion applied to the axle of the engine; but the eccentric dispenses with the crank which would have been necessary in the axle.

However, as by the disposition of the engine the slide-rod is not in the same plane with the axle, the eccentric does not communicate directly the motion to the slide-rod itself; the motion is communicated to that rod by means of the cross-axle K, and the two arms KL′ and Kl′ which are fixed to it; and the consequence is, that when the eccentric goes back, the slide-rod l advances, and *vice versa,* as may be seen on the figure.

A comparison between figs. 9 and 10, the difference of which is a quarter of a revolution, will make the above-mentioned effects perfectly intelligible.

By examining the motion of the slide (fig. 10,) it will be seen that, while passing from one of its situations to the other, and when it happens to be exactly in the middle position, there occurs one instant during which all the passages of the steam are shut together. This effect takes place at the moment the slide changes the passages of the steam, and corresponds with the point where the piston changes its direction. This coincidence can only take place because, setting aside the little lead of the slide, the radius of the eccentric is at right angles with the radius of the crank. In fact, the slide is necessarily thus in its middle position, that is to say, changing the communications of the steam, at the same time as the piston is at the bottom of the cylinder, ready also to alter the direction of its motion. This correlativeness of motions is clearly exhibited in the figure.

The particular advantage of the eccentric being thus placed at right angles with the crank is, that the eccentric is in full action when the crank is on its centre, or the piston at the bottom of the cylinder, that is to say, that the slide is in its most rapid motion just at the moment that it is to open or shut the passages; which circumstance is necessary to prevent time being lost in the alternate effect of the steam.

Section 8.—*Of the Drivers.*

Until now we have spoken as if there were only one slide, but, having said there were two cylinders, it is clear that there must be a slide, and consequently an eccentric for each of them. On the other hand, the two pistons alternating one with the other in their motion, that is to say, acting upon two cranks perpendicular to each other, as has been explained, the radii of the two eccentrics must necessarily stand also at right angles with each other. This disposition may be seen in figs. 11 and 12, where the piece forming the two eccentrics is represented in front. To make it more clear it is marked by hatchings.

This piece must, as has been said, move with and be carried along by the axle. However, if it were permanently fixed on the axle, its position might suit when the engine is to go forward, and not when it is to go backward; for it will be seen that, for these two motions, the eccentric must be fixed in two different positions.

This piece is therefore loose upon the axle, like a pulley on its axis, but it can be fastened to it at will. To that effect its side faces have two apertures or eyes, represented at O and O′; and the axle itself carries two pins rr', which are called drivers. The eccentric being placed on the axle between the two drivers, it is easy to push it by means of a lever, either against one or against the other, until it enters into the aperture designed for it; so that, from that moment, the eccentric may be drawn along by the axle. Moreover, if these two drivers be placed in such a manner that one may suit to the progressive, and the other to the retrograde motion of the engine, we shall, by disengaging the eccentric from the one and carrying it to the other, be enabled to make the engine go either forward or backward at pleasure.

There is no difficulty in fixing the place that the eccentric must occupy on the axle, either for the progressive or the retrograde motion.

Let us suppose that, by pushing the engine gently along the rails, we bring one of the pistons to be just in the middle of the cylinder, and that precisely at the same instant the crank, on which the piston acts, is in its vertical position above the axle, as in fig. 3, it is clear that, to make the engine go forward, the steam must push the piston forwards, for then the piston will carry along with it, in the same direction, both the crank and the wheels; consequently, the slide must admit the steam by the passage No. 1, or be drawn forward as it is represented here, which, by referring to fig. 9, requires that the radius of the eccentric be horizontal, and placed at the back of the axle. This is, therefore, the point at which the driver must fix the eccentric for the progressive motion.

The engine remaining in the same position, let us suppose that we wish, on the contrary, to dispose it for the retrograde motion. The steam must arrive on the opposite face of the piston, that is to say, that the passage No. 2 must be opened to it, which supposes that the slide is pushed backwards, and consequently that the eccentric is in front. It is therefore horizontally, and in the front of the axle, that the eccentric must be fixed by means of the driver.

This is exactly the position of fig. 12. By observing the right hand crank, we see that while that crank is vertical and above the axle, the driver *r* on the right side, and the aperture that receives it, are behind, and hidden by the axle; consequently, the eccentric is horizontal, and in front; a position which, as we have seen, suits a retrograde motion. The driver *r* is thus placed for the retrograde motion, keeping the eccentric in that position.

If we now suppose, on the contrary, that the eccentric be pushed against the other driver *r′*, the corresponding aperture of the eccentric being at O′, that is to say not being in front of the driver, the consequence will be that, the eccentric not stirring out of its place, the axle will be forced to turn half round before the driver can enter into the aperture. From this follows, that if we continue to examine the right crank, it will be found to have arrived *under* the axle,

while the eccentric will still be in front, which is the position that suits the progressive motion; for it is the same as the one we have explained above, of the crank being above the axle, and eccentric behind.

Thus, we see that the two drivers r' and r, in figs. 11 and 12, being placed at right angles with each other, and with the cranks of the axle, are in a proper position; one for the progressive, and the other for the retrograde motion of the engine.

These two drivers being fixed on the axle, one on one side, and the other on the other side of the eccentric, it is clear that by pushing that eccentric, by means of a lever, either on one or on the other of the two drivers, the effect of the steam on the piston will immediately be to carry the engine either forwards or backwards, according to the driver with which it has been thrown in gear. The lever, which causes the change of position of the eccentric, is placed in such a manner as to present its handle within the reach of the engine-man on the board on which he stands.

Besides these several dispositions, in order that the man who directs the engine may himself and of his own accord move the slides, independently of the motion of the axle, the shafts of the eccentrics are not invariably fixed to the slide-rods. They are only fastened to them by a notch L', figs. 13 and 14. By means of a lever acting on the small rod $m'o$, the engine-man can raise the shaft of the eccentric and disengage it from the notch, as may be seen in fig. 14; then the slides are at liberty to move independently of the axle; consequently, it is easy, by means of two handles represented by PP in fig. 1, and connected with slide-rods, to give to those slides the required motion.

Section 9.—*Of the Water-Pumps.*

Under the body of the engine are two pumps p, fig. 1, the use of which is to replenish the boiler with water. Each of them is placed immediately under the piston-rod of each cy-

linder, and is worked by it. Each pump sucks a part of the water of the t nder into the cylinder of the pump, and, on the other hand, forces it from the cylinder of the pump into the boiler, in the usual way. By having two pumps the replenishing of the boiler is secured, as, in case one of the two were to get out of order, the other may easily supply its place.

The valves of these pumps are ingeniously made of a small metallic sphere, resting on a circular seat, on which it always exactly fits. Their action takes place by rising within a cylinder, the sides of which are pierced with four apertures for the passage of the water. One of these valves is represented in fig. 15. The water is introduced through *a* from the interior of the cylinder, under the spherical ball which it raises, and is diffused in the body of the pump by the apertures *b*, *b*. This form of a valve never misses its effect; and the pumps, which, in the beginning, were continually out of order, are free from that defect, since Mr. Melling, of Liverpool, first introduced that sort of valve.

Section 10.—*Of the Steam-Regulator.*

The regulator, of which we have spoken above, and by means of which the passage leading from the boiler to the cylinders may be more or less opened, is represented in figs. 32 and 33. It simply consists of two metallic disks placed above and exactly fitting each other, both having an aperture of the same size. The inferior disk is immoveable, and shuts the pipe through which the steam escapes. The superior disk is moveable, by means of a handle T, which projects out of the engine; the stem *r* of the handle passes through the moveable disk, and enters the other in its centre, so as to keep them both in a right position over each other. In fig. 32, these two disks are distinguished from each other by hatchings running a different way. By making the superior disk K, by means of the handle T, move circularly on the inferior disk, the two apertures may be brought to

correspond exactly with each other, as in fig. 32, and then the passage is entirely open. If only partially moved, as represented by the dotted lines in fig. 33, the passage is only partially opened; and when the two apertures do not correspond at all, the communication is completely intercepted: when the passage is thus shut, it is the steam itself that keeps the two disks in immediate contact with each other, by pressing with all its force on the superior disk.

This regulator may also be constructed in a different way. It is sometimes made in the form of a common two-way cock, the steam coming from above; but the preceding description is the one most commonly used.

Section 11.—*Of the Joints or rubbing parts.*

In all the joints of any importance, the oil is fed without interruption by means of a cup, with a wick-syphon, placed above the joint as at *m* in fig. 6. This cup is made in the form of a school-boy's ink-horn, so that the velocity of the motion may not spill the oil; and there is at the bottom of it a small tube, penetrating to the entrance of the joint. A cotton-wick dipping in the oil of the cup passes in the tube, and, sucking continually the oil out of the cup, drops it into the joint without interruption.

Section 12.—*Of the Fire-Grate.*

The grate in the fire-place is not made of a single piece. It is formed of separate bars (fig. 31,) which are placed next to each other at the bottom of the fire-place, where they are supported by their two ends. The advantage of this arrangement is, the facility it affords of replacing them individually by new ones, when they are worn out by the intensity of the fire. Besides, if any accident should happen to the boiler, and make the water run off unexpectedly, thus endangering the engine, one may, by means of a crooked poker, easily turn the bars upside down, and con-

sequently extinguish immediately the fire by letting it fall on the road, with the bars that supported it. It is also thus that every evening the fire-box is emptied, after the engine has finished its work.

Section 13.—*Of the places occupied by the different parts.*

We shall complete this description, by showing on the whole engine as represented in figs. 1 and 2, the places occupied by the different parts of which we have spoken.

A, Part of the boiler containing the fire-box.
BB, Stand for the engine-man and his assistant.
C, Chimney of the engine.
D, Place of the cylinders.
E, First safety-valve, with lever and spring-balance, as will be explained hereafter.
F, Second safety-valve, constructed in the same manner.
G, Glass-tube.
H, Gauge-cocks.
I, End of the eccentric-rod.
J, Horizontal guides for the head of the piston-rod, so as to ensure its motion in the exact direction of the axis of the cylinder.
K, Cross axle, communicating the motion of the eccentric-rod to the slide-rod, by means of the arms KL′ and Kl', which are fixed upon it (see figs. 9 and 10.)
L′, Notch for throwing in gear the eccentric-rod with the cross-axle which works the slide-rods.
MM, Rod by means of which the engine-man can raise the eccentric-rod, and throw it out of gear with the cross-axle which works the slides. This is performed by means of the arms *m* and *m′* connected together. When the engine-man pulls the rod MM, he causes the arm *m′* to raise, and with it the small rod *m′ o′*, which lifts the eccentric-rod out of gear with the arm KL.

N, Handle, by means of which the engine-man pulls the rod MM, so as to produce the aforesaid effect.

PP, Handles to move the slides when they are thrown out of gear with the eccentrics. These handles, acting upon the cross-axle Q, move the cross-heads RR which are fixed to it. This motion is communicated by means of the rods SS to the cross-heads *rr*, which act upon the axle working the slides.

T, Handle of the regulator, to open more or less the aperture through which the steam passes from the boiler to the cylinders.

V, Steam chamber, or reservoir, in which the steam is confined till it can escape through the aperture of the regulator, and penetrate into the cylinders.

U, Man-hole, or aperture, closed by a strong iron plate, and large enough to admit a man into the interior of the boiler, when necessary.

XX, Iron knees, by which the boiler is fixed to the frame of the carriage.

ZZ. Springs resting at *aa* on the chairs of the wheels, by means of vertical pins passing through holes in the frame of the engine. One end of the pin resting on the back of the spring, and the other on the upper side of the chair; the whole weight of the machine is thus supported by the wheels, but through the intermediate action of the springs.

bb, Guides for the chair of the wheel to slide up and down, according as the spring bends more or less under the weight of the engine. The upper part of the chair is scooped out to form a small reservoir for oil. This reservoir, as well as the above-mentioned cups, contains a tube and a syphon-wick, for feeding constantly the oil upon the axle, at its rubbing point with the axle-box.

c, Flexible tube made of hemp cloth, but supported within by a spring, and through which the water arrives from the tender to the pump of the engine, when a cock fixed to the tender is opened.

p, Water-pump of the engine, which is constantly set in motion by a connexion with the piston-rod of the corresponding cylinder, but which cannot force any water into the boiler, unless a cock which lets the water come in from the tender be opened. The cock is not marked on the figure.

p', Handle and rod of the safety-cock of the pump, serving to ascertain whether the water really arrives in the cylinder of the pump. This cock leads without, so that when it is open and the pump has its proper effect, a small jet of water may be seen issuing from it, which shows that the pump works right.

ee, Pad, stuffed with horse-hair and covered with leather, to deaden the shocks the engine may give or receive.

f, Cock by means of which the water that is sometimes carried from the boiler to the cylinder may be forced out by the effect of the steam.

g, Opening made in the double casing of the fire-box, and closed by a screw bolt. In withdrawing this bolt, a cleaning-rod may be introduced into the double-casing; and, by means of a forcing-pump, water may be injected with force, to cleanse out the clay sediment left by the boiling of the water. This cleaning is usually performed once a-week.

h, (fig. 2.) Moveable plate, or door, opening the interior of the chimney compartment, by which the end of the tubes of the boiler, the cylinders, the slides, and the steam-pipes leading from the boiler to the slide-boxes, or from the slide-boxes to the chimney, are visible. This door is opened when it is necessary to regulate the slides, as we shall see hereafter.

ARTICLE II.

OF THE PROPORTIONS OF THE ENGINES.

SECTION I.—*Of the Dimensions of the parts from which the power of the Engine is derived.*

Such is the construction of the locomotive engines employed on the rail way between Liverpool and Manchester. We have made use for our experiments of no other engines but those. To give a complete idea of them, we have now only to state the dimensions of some of the parts, on which the power of the engine more especially depends, as will be seen farther down.

The engines on the Liverpool Railway may be ranked in five different classes, as follows:—

Classes.	Diameter of the cylinder.	Stroke of the piston.	Wheels.	Weight.	Effective pressure per square inch in the boiler.
	inches.	inches.	feet. inches.	tons.	lbs.
1 - -	14	16	4 6	12	50
2 - -	12	16	5	12	50
3 - -	11	16	5	8 to 9	50
4 - -	11	18	5	8 to 9	50

In the fifth class come the first engines used by the company at the opening of the railway; their cylinders are ten inches in diameter, and under; the stroke of the piston, the wheels, and the weight of the engine vary accordingly. But at present they have nearly ceased to be used on the railway; they scarcely ever undergo any repairs, and none of them will figure in our experiments. We need therefore not enter into any particulars concerning them.

Among the thirty-two engines that have been constructed for the company, and of which thirty are still in their possession, there are

2 of 14 inches (diameter of the cylinder.)
4 of 12 do.
16 of 11 do. with a sixteen-inch stroke.
2 of 11 do. with an eighteen-inch stroke.

The eight others are of inferior proportions, and rank in the fifth class which we mentioned above.

They are all at the *effective* pressure of 50 pounds per square inch on the boiler.

In proportion as we shall make use of the engines, we shall state more particularly their names, weight, and power.

Section 2.—*Of the expression of the power of Locomotive Engines.*

It is by these dimensions that it is customary to express the power of locomotive steam engines. We shall see in the course of this work, that to render that expression complete and really sufficient to show the effect of the engine, under all circumstances, two other elements ought still to be added to them, viz., the friction of the engine, and the evaporating power or extent of heating surface of the boiler. However, such as they are, they give a tolerably exact idea of the power of locomotive engines.

As to the mode used for stationary steam-engines, which consists in expressing their power by the effect produced, and comparing it to the work a horse would perform, it is easy to conceive such a mode which is very deficient in all cases, as we shall see, is at all events not applicable to locomotive engines, for the following reasons:—

1. Because the power of a locomotive engine does not depend alone on the force residing in the steam; it depends also on the weight of the engine, which produces a greater

or less adhesion of the wheels to the rails, and consequently the locomotive of a more or less considerable load.

2. Because the engine must move at different rates of speed. Now, besides the weight of the load, the engine must also move itself along by overcoming its own friction. That friction, entering therefore as an invariable quantity in the resistance, from which it must always be first of all deducted, it limits, according to each velocity, the final power remaining in the engine as applicable to the load. The consequence of this is, that, if we were to express the power of the engine by the effect produced, we would find that measure different at each degree of speed at which we would consider the engine.

3. Because locomotive engines moving three or four times quicker than horses can do, it would be but an unintelligible fiction to pretend to assimilate them to horses.

Section 3.—*Dimensions of the Fire-box and Boiler in twelve of the best Locomotive Engines of the Liverpool and Manchester Railway.*

According to the remark we have made here above, and which will be confirmed in the course of this work, any expression of the power of a locomotive engine becomes imaginary, unless its evaporating power, or the extent of the heating surface of its boiler, be given at the same time. It is, in fact, in the fire-box and boiler that resides the real source of the power of the engine. From thence results all the effect produced. The cylinder and other parts are the means of transmitting and modifying the power; but what could be their effect, if that power itself did not exist?

To complete, therefore, the proportions already given above, we shall add here a table of the dimensions of the fire-box and boiler in the different engines to which we shall have occasion to refer. At a future period, our experiments will enable us to replace this complex expression by

the simple expression of the evaporating power of those same engines.

The two most important columns of this table, are those which show the extent of surface exposed to the radiant heat of the fire, and to the communicative heat of the flame.

It will be seen hereafter, that, with a boiler of those dimensions and of such a form, the engines are able to evaporate about a cubic foot of water per minute, or a pound of water per second, at the effective pressure in the boiler of 50 lbs. on the square inch.

Comparing with each other the extent of surface exposed in each engine to the action of the heat, a great distinction must be made between the surfaces exposed to the immediate and radiating action of the fire, and those which only receive the heat by communication, during the passage of the hot air from the fire-place to the chimney. An experiment made by Mr. Robert Stephenson is mentioned in Wood's work, p. 403, from which it appears that the two effects stand to each other in a ratio of three to one. Circumstances did not allow us to repeat the experiment.

It was made with a boiler similar to those described above, but the upper part of which had been taken off, and the water exposed to the direct action of the fire, separated from that which receives only the communicative heat; the water was put into ebullition, and, after it had boiled for some time, the water that had been evaporated in each compartment was measured. It was then ascertained that each square foot of surface exposed to the heat of the radiating caloric, had evaporated three times as much water as the same extent of surface exposed to the hot air. This proportion may be considered as sufficiently established by the experiment, in so far at least as regards a boiling apparatus, similar to those described above.

DIMENSIONS OF THE FIRE-BOX AND BOILER OF TWELVE OF THE BEST LOCOMOTIVE ENGINES OF THE LIVERPOOL AND MANCHESTER RAILWAY.

Name and number of the engine.	Diameter of the cylinder.	Lgth. of stroke of the piston.	Diameter of the boiler.	Lgth. of the boiler and tubes.	Number of tubes.	Diameter of the tubes.	Area of the firebox or surface exposed to the radiating caloric.	Area of the tubes, or surface exposed to the contact of the flame and heated air	Area of the fire-grate.	Quantity of fuel contained in the fire-box to the hgt. of the lowest row of tubes.	Diameter of the chimney.	Remarks.
	inches	inches	feet.	feet.		inches	sq. feet.	sq. feet.	sq. feet.	cub. feet.	inches.	
SAMSON - - No 13	14	16	3.50	7	140	1⅝	40.20	416.90	7.50	10.87	12.50	This engine is now being reconstructed.
JUPITER - - " 14	11	16	2.75	6.50	79	do.	36.06	226.80	6.08	11.12	12	
GOLIATH - - " 15	14	16	3.50	7	132	do.	40.31	407	7.50	10.87	12.50	
VULCAN - - " 19	11	16	3	6.50	107	do.	34.45	307.38	6.50	7.64	13.50	
FURY - - - " 21	11	16	3	6.50	107	do.	32.87	307.38	6.12	8.13	13.50	The tubes of this engine are very thin.
VICTORY - - " 22	11	16	3	6.75	97	do.	37.63	278.53	6.27	11.47	13.50	
ATLAS - - " 23	12	16	3	7.78	65	do.	57.06	217.88	9.20	13.06	12	
VESTA - - " 24	11⅛	16	2.75	7	80	do.	46	256.08	7.06	11.72	11.50	
LIVER - - - " 26	11	16	3	6.50	97 {70, 27}	1¾, 1⅜	39.66	284.01	8.11	12.48	13.50	
AJAX - - - " 29	11	18	2.75	6.66	63	2	32.64	228.14	6.08	8.32	13.50	
LEEDS - - " 30	11	16	3	6.50	107	1⅝	34.56	307.38	6.19	8.23	13.50	
FIREFLY - - " 31	11	18	3	7.50	110	do.	43.71	362.60	7.16	14.30	13.50	The fire-box of this engine is at present being altered.

Section 4.—*Of Locomotive Engines of a different construction.*

The description given above is applicable to the most powerful engines constructed until the present time. That form is exclusively adopted on the Liverpool and Manchester Railway.

On other lines, engines of different constructions are to be found. The railroad from Stockton to Darlington being used for a different service, that is to say, for a more moderate speed, it may be proper to give here an idea of the engines used on that line.

The company possess twenty-three locomotive engines of different models, from the oldest to the most recent ones.

In some of them the fire passes through the boiler in a single tube, which serves as a fire-box, and communicates directly with the chimney. In some others the tube bends round in the boiler before it reaches the other end, and comes back to the chimney, which, in that case, is placed next to the door of the fire-box. In others, the tube or flue, when it reaches the end of the boiler, divides and returns towards the chimney, as two smaller tubes. In some, the fire being still placed in an internal flue, the flame returns to the chimney by means of about 100 small brass tubes, on a principle similar to that of the Liverpool engines. Lastly, three of them are constructed on the same model as those of Liverpool.

The company carries both passengers and goods. They first travel with a speed of twelve miles, and the second of eight miles an hour. Of the different forms of boilers, those only with a set of small tubes suit for carrying passengers, the others cannot generate a sufficient quantity of steam. But when a speed of eight miles per hour only is required, and for an average train of twenty-four wagons, which, in going up the line empty, are equal to a load of about sixty tons on a level ground, the most convenient boilers have been found to be those with one returning tube. They ge-

nerate a sufficient quantity of steam for the work required of them, and have the advantage of being cheap in regard to prime cost and repairs, as their form is simple, and they are entirely made of iron, whilst the tube boilers require the use of copper.

Besides the difference in the form of the boilers, the other parts of the engine differ also. The cylinders are placed on the outside, and in a vertical position. The motion is not communicated from the piston to the engine by a crank in the axle, but by a rod on the outside of the wheel, resting upon a pin fixed in one of the spokes. Those engines have in general six equal wheels, of four feet diameter each. Two of the wheels are worked by the cylinders, as has been just explained; and the four others are attached to the first by connecting rods, that cause them to act all together.

The weight of these engines varies. Setting aside the three which we have mentioned as being on the model of the Liverpool ones, and which weigh only about five tons and a half, the average weight of the others is from ten to twelve tons.

All those engines are supported on springs. In some of the older ones, the water of the boiler, pressing upon small moveable pistons, and pressed itself by the steam contained in the boiler, was intended to supersede the springs; but though that system displayed a great deal of ingenuity, the spring it formed was found in practice to be too variable, and the system was given up.

The usual proportions adopted for the engines on that railway are the following:

Cylinder	14½ inches.
Stroke	16—
Wheels	4 feet.
Weight	11 tons.
Effective pressure . .	48 lbs. per square inch.

The pressure, however, varies according to the ascertained solidity of the boiler. When the sheets of which it is formed begin to grow very thin, the pressure is sometimes reduced to 36 lbs. only per square inch; in other circumstances, it is, on the contrary, increased to 60 lbs.

CHAPTER II.

OF THE PRESSURE IN STEAM ENGINES.

ARTICLE I.

OF THE PRESSURE CALCULATED ACCORDING TO THE LEVERS AND THE SPRING-BALANCE.

SECTION 1.—*Of the principle on which that calculation is founded.*

When an elastic fluid is confined in a closed vessel, it produces in every direction on the sides of the vessel a pressure, which is the result of its elastic force, and which gives the exact measure of that force. If, the vessel being already filled with steam, a fresh quantity is continually added, the elastic force of the steam will augment more and more, and consequently also the pressure it produces on every square inch of the surface of the vessel. Now, if at one point of the vessel there be an aperture, closed with a moveable piece supporting a certain weight, it is clear that, as soon as the steam contained in the vessel produces upon the moveable plate a pressure equal to that of the weight which holds it down in the opposite direction, the plate will begin to be lifted up; the passage will then be opened, and the steam escaping through the aperture, will show that its pressure was equal to the weight that loaded the plate or valve.

It must, however, be observed, that the resistance which opposes the egress of the steam does not consist only in the

weight that has been placed on the valve. Besides that weight, the atmosphere produces also on the valve a certain pressure, as well as upon every body with which it comes in contact. That pressure is known to be equal to 14.7 lbs. per square inch. It is therefore the weight, added to the pressure of the atmosphere, that gives the real measure of the elastic force of the steam; while the weight alone represents only the surplus of the pressure over the atmospheric pressure, or what is called the *effective* pressure of the steam. Consequently, when a valve has a surface of five square inches, and supports a weight of 250 lbs., which, divided between the five square inches, gives a resistance of 50 lbs. per inch, that amount of 50 lbs. expresses the *effective* pressure of the steam, a valuation frequently made use of on account of its convenience for calculation, whereas, 64.7 lbs, is the real resistance opposed, and therefore the real pressure of the steam.

This is the principle on which are established the means of judging the amount of pressure in locomotive engines. However, as those engines are required to work with at least 50 lbs. effective pressure per square inch, and as, in order to give passage, if necessary, to all the steam generated in the boiler, a valve must not have less than 2½ inches diameter, or 5 square inches surface, it follows of course that if a weight is to be applied directly upon the valve, it must be equal to 250 lbs. Such a weight would afterwards render it very difficult to lift up the valve with the hand, which frequently becomes necessary in the working of the engine, and particularly to ascertain whether the valve may not have contracted an adhesion to its seat which would make it useless.

It was therefore necessary to produce the pressure by means of a lever; for if we suppose the lever divided in the proportion of 5 to 1, a weight of 50 lbs. suspended at the end will be sufficient to produce the required pressure without the disadvantage of having a considerable weight to move. But, on the other hand, as, in the rapid motion of

the engines, a weight, suspended at the end of a lever was found to be continually jerking, and consequently opening and shutting continually the valve, the weight was replaced by a spring, and that is the manner in which the valves are at present constructed.

Section 2.—*Of the Levers and Spring Balance.*

It will easily be conceived that no exact calculation can be established of the power of locomotive engines, without knowing exactly the pressure of steam in the boiler, which is the intenseness of the propelling force of the motion. If we were to depend on the *nominal* pressure of the engine, that is to say, the pressure declared by the constructor, great mistakes might be incurred: for it sometimes happens that, with a view to give a locomotive engine the appearance of executing more than others, though at the same pressure, its pressure is declared to be 50 lbs. per square inch, whilst it really is 60 or 70 lbs. Moreover, the calculation of the pressure is generally so incorrectly made, that scarcely any dependence can be placed upon it.

We have therefore been obliged to make a particular study of that part of our subject.

We shall first give the manner of ascertaining the pressure by weighing and measuring the different parts of the valve apparatus, in case one should have no mercurial gauge. We shall afterwards show the cause of some mistakes which may be incurred by using that mode of calculation, and which are avoided by using the mercurial steam-gauge. Lastly, we shall point out the uncertainty to which also that instrument is liable, and we shall propose another to be used instead of it.

We have said, that, to produce on the valve a great pressure without being encumbered with a considerable weight, a lever is employed. M (fig. 16) being the boiler, and S the valve, C is a fixed point to which is fastened one of the ends of the lever BC. The lever presses at the point A on the valve by means of a pin, and at the point B it supports a

weight or to speak more accurately, it is drawn by a spring equal to a given weight.

The diameter of the valve, the proportions of the lever, and the weight suspended at the point B, or at least the weight represented by the tension of the spring being given, it will be easy to deduce from them the pressure resulting on each square inch of the surface of the valve. And, *vice versa*, it will also be easy to know what weight ought to be applied to the point B, in order to produce at A a given pressure. For, if P represent the weight suspended at B, that weight will produce on A a pressure $P \times \frac{BC}{AC}$ which will consequently be the whole pressure produced on the valve; and if S represent the surface of the valve in inches $\frac{P \times \frac{BC}{AC}}{S}$ will be the pressure produced on each square inch of the surface of the valve.

The levers and valves used by the different constructors of engines vary considerably in their proportions. But among those proportions there is one, first used by Mr. Edward Bury, of Liverpool, which possesses an uncontested advantage over all other combinations of that sort. It consists in taking for the proportions between the two branches of the lever the ratio of the area of the valve to the unit of surface. By that means the weight P suspended at B gives immediately the pressure produced on the valve per unit of surface. Supposing it should be required to establish a valve of $2\frac{1}{2}$ inches diameter, which make very nearly 5 square inches surface, and that in consequence, the ratio between the two branches of the lever has been taken as 5 to 1, that is to say, that $\frac{BC}{AC}=\frac{1}{5}$; P expressing the weight suspended at B, it is clear that the pressure produced at A will be $P \times \frac{BC}{AC}=5$ P. This will, therefore, be the total weight on the valve, and the surface of the valve being 5 square inches, the weight or pressure per inch

will be $\frac{5\,P}{5} = P$. The same would take place if, having a valve 3 inches in diameter, which gives 7 square inches for the surface, the ratio between the branches of the lever were to be taken as 7 to 1.

We have said that, to the weight which ought to be suspended at the end of the lever at B, is substituted the equivalent pressure of a spring. This spring is a spiral, which by being more or less compressed, is able to support in equilibrium, and consequently to represent larger or smaller weights. In other words, it is a spring balance, such as is used for weighing in daily occurrences.

This balance consists of a rod T (fig. 16) which is held in the hand, and to which is fastened a plate with a narrow oblong aperture in it. Behind this plate, and in a cylindrical tube, is a spring, the foot of whieh rests on the basis L, which is fixed to the plate. At its other end, this same spring is pressed by a moveable transverse bar *mn*. At the bottom of the apparatus is a rod P, to which are fastened the objects that are to be weighed. The prolongation of the bar *mn* projects through the aperture of the plate, and is terminated by an index which appears on the outside, and which slides up and down the aperture, in proportion as the spring is more or less compressed. Divisions are engraved along that same aperture. In order to mark them, known weights of 1 lb., 2 lbs. &c., are successively suspended at P, and according as those weights, by pressing on the spring, cause the index to rise, the corresponding divisions are marked. The consequence of this is, that when an object of unknown weight is suspended at P, and makes the index rise to the point marked 10, that is to say, to the same point to which a known weight of 10 lbs. made it rise, we conclude that that object also weighs 10 lbs. This is the sort of balance which is used for measuring the pressure in locomotive engines. We see that, by taking it off from the engine, and suspending known weights to it, the divisions may easily be verified, after the balance is graduated.

When on the engine, the foot P of the balance, where the object to be weighed would be suspended, is fixed in a solid manner to the boiler; and the rod T, which would be held in the hand in common weighing, is fastened to the end of the lever. This rod passes through an aperture cut through the end of the lever, and is fixed above it by a screw which rests upon the lever. When it is required that this balance shall produce a pressure of 10 lbs., nothing more is necessary than to lower the screw until the spring rises to the point marking 10 lbs., and the same for any other weight.

Vice versa, the steam being in the boiler at an unknown degree of pressure, if we loosen gradually the screw until the steam begins to raise the valve, that is to say, until its pressure stands in equilibrium with the pressure of the spring, the pressure of the steam will be known, for the degree then marked by the index will show the weight which is equal to it.

Section 3.—*Of the corrections to be made to the Weight marked by the Spring-balance.*

The mode we have just explained is the one commonly used to calculate the pressure on the valve. However, it will easily be conceived, by the manner in which the spring-balance acts upon the valve, that, to know the pressure which really opposes the egress of the steam, it is not sufficient to read the degree where the index stops, and to calculate the effect produced at the end of the lever, as we have done above. In fact, first, besides the weight represented by the spring, and which would be suspended at the end of the lever, it is clear that the weight of the lever itself causes a certain degree of pressure; for before the steam is able to raise an ounce of the spring, it must raise the whole weight of the lever. The same takes place in regard to the disk of the valve, which must be raised before the steam can have any action on the balance. 2. When any object is weighed with the hand, that object is suspended at the bottom of the

balance, but then the hand supports the upper part, that is to say, the rod, with the spring to which it is fastened; and that effort is not taken into account, because it does not make a part of the weight. Here, on the contrary, the rod, the screw, and the spring, are an additional weight really suspended at the end of the lever, over and above the pressure marked by the spring; they must all be raised before the spring can be pressed upon in any way, and can register any effort; they must therefore be taken into account. The true pressure which takes place on the valve will consequently not be known, until are added to the weight marked in the balance: 1. The pressure produced by the weight of the lever at the place of the valve: 2. The pressure produced at the end of the lever by the weight of the rod and spring of the balance.

1. To know the effect of the lever on the valve, the lever must be unfastened from the balance; a string must be wound round the pin A, or passed through the aperture of the lever at that place, and then, with another spring-balance, the lever must be weighed by means of the string. It is clear that the weight marked by the second balance will be the pressure produced by the lever at the place of the valve; to that must be added the weight of the disk of the valve, which must also be weighed separately, by putting it into the basin of a common pair of scales. When the levers have a total length of 3 feet with the usual thickness, they commonly weigh 27 lbs. or 28 lbs. at the place of the valve. The disk of a valve of 2½ inches diameter, and half an inch thick, weighs in general about 10 ounces. There is therefore a weight of 28½ lbs. to be divided on the whole surface of the valve; so that if that surface is equal to 5 square inches, it makes 5½ lbs. per square inch. When the levers are only 15 inches long, they generally weigh 7½ lbs. at the place of the valve, which makes, together with the disk, 8 lbs. 2 oz., and, divided between the 5 square inches, a little more than 1½ lb. per inch.

2. To know the weight of the part of the balance sup-

ported by the lever, the balance ought to be taken to pieces, and the spring with its rod weighed separately. However, this operation may be avoided by taking the balance in one's hand, and suspending it in the contrary direction in which it is placed in the common act of weighing, that is to say, with the foot above and the rod below; the weight marked by the index will then be equal to the difference between the weight of the rod and spring, and the weight of the foot, If, therefore, the total weight of the balance be known, which is easy, by placing it in the basin of a common pair of scales, the weight of each of its parts may easily be calculated, and consequently also the weight of the rod and spring.

In fact, the degrees having been marked on the balance when in its usual situation, zero was inscribed at the point where the index stood when the spring bore no weight at all, or more exactly when it only bore the weight of the foot. Afterwards fresh weights were successively added, and for each of them the corresponding number was inscribed on the plate, always omitting the weight of the foot, which in fact ought not to be reckoned. The numbers inscribed on the plate represent, consequently, the real tension of the spring, less the weight of the foot of the balance. Now, by turning the balance upside down, the spring is drawn by the weight of the rod and spring which it then bears. If it had borne a weight equal to that of the foot, it would have marked zero; if, therefore, it marks 2 lbs. or 3 lbs., the rod and spring weigh 2 lbs. or 3 lbs. more than the foot.

Supposing thus: B to be the total weight of the balance, T the weight of the rod and spring, and P′ the weight of the foot; if the balance turned upside down shows m weight, we shall have

$$m = T - P';$$

but, on the other hand, the weight of the balance is equal to the weight of its two parts, or

$$B = P' + T:$$

adding therefore together these two equations, we find

$$B + m = 2T, \text{ or } T = \frac{B + m}{2}.$$

When the valves have a leader of 15 inches only, the balance used weighs generally 4 lbs., and when turned upside down, it marks $1\frac{1}{2}$ lb; so in that case the weight of the rod and spring is

$$T = \frac{4 + 1.5}{2} = 2.75 \text{ lbs.}$$

which is the weight to be added at the end of the lever; that is to say, to the weight already marked by the balance.

When the valve has a lever of 3 feet, the balance requires smaller divisions. It usually weighs only 2 lbs., and, turned upside down, marks $1\frac{1}{2}$ lb., which gives in that case for the weight of the rod and spring

$$T = \frac{2 + 1.5}{2} \quad 1.75 \text{ lb.:}$$

adding therefore those weights to those marked by the index of the balance, and taking besides into account the weight of the lever, as mentioned above, we shall then have the real pressure produced by the whole apparatus on the valve. Dividing it by the area of the valve, the result will be the pressure effected upon each unit of surface.

From this we see that, with a long lever, the error of pressure per square inch may amount to 7 lbs. or 8 lbs., and that, even with a short lever, it may be 3 lbs. or 4 lbs., which is still considerable.

Keeping the preceding notation, that is to say, P being the weight shown by the index, T the weight of the rod and spring, L the weight of the lever, weighed as mentioned above, and D the weight of the disk, lastly, BC and AC being the arms of the lever, and S the surface of the valve in square inches, the pressure produced per unit of surface will be

$$\frac{(P + T)\frac{BC}{AC} + L + D}{S}$$

It is for not having taken these considerations into account that we find so often on locomotive engines spring-balances, which are supposed to be fixed at 50 lbs. pressure per inch, but which are really fixed at 55 lbs. or 60 lbs. We shall soon have frequent occasion to apply and verify these principles, which by that means will be rendered perfectly clear.

Section 4.—*Of the Mitre of the Valves.*

These are not the only causes from which errors may result. There are two others which are frequently met with in the valuation of the pressure of locomotive engines, and which are not so easy to correct as those we have just mentioned.

In order that the valves may exactly close the opening to which they are applied, without being subject to contract an adhesion with the seat that supports them, it is necessary to make them slightly conical, or at least with a slanting border. When these valves rest upon their seat, which they completely fill, it is very clear that the steam can only act upon their inferior surface; consequently, the area we have here above expressed by S, must be taken after the *inferior* diameter of the valve. By calculating in that manner, the exact pressure will indeed be found for every case in which the valve still touched the seat, or, if raised at all, was only so for an instant, or in a very small degree; but whenever the steam being generated in greater quantity than it is expended by the cylinders, escapes with force through the valve, it raises considerably the disk of the valve; the consequence then is, that, instead of acting on the inferior surface of the valve, it evidently acts on a greater surface, and which is the greater the more the valve is raised. For instance, in fig. 20 it acts on the surface *cd* instead of acting on *ab*. In that case the area S ought to be calculated on *cd*, and not on *ab*. But how are we to know *cd*, unless we calculate it by the raising of the valve, which is a very difficult,

if not an impossible, operation? Moreover, the difficulty is complicated by the circumstance that, from *a* to *b* the pressure of the steam acts directly to raise the valve; but from *c* to *a* and from *b* to *d* the action of the steam takes place only in a lateral direction, and according to an angle, which varies in proportion as the valve is more or less raised.

The effect of this alteration in the diameter of the valve, which at first sight appears to be of very small consequence, is in fact very considerable. Let us suppose, for instance, that we have a valve of 2.50 inches diameter at the bottom, and 3 inches at the top, of which we shall find several examples hereafter. Let us farther suppose that, by the effect of the blowing of the steam, the valve has been raised so as to have increased its real diameter only by one eighth of an inch; that is to say, that it is become $2\frac{5}{8}$ inches instead of $2\frac{1}{2}$ inches, or 2.625 inches instead of 2.50 inches. The surface of the circle being expressed by $\frac{1}{4}\pi d^2$, where d stands for the diameter and $\pi = 3.1416$, the proportion of the circumference to the diameter, the surface of the valve, which was at first

$$\frac{1}{4} \times 3.1416 \times \overline{2.5}^2 = 4.91 \text{ square inches,}$$

has become

$$\frac{1}{4} \times 3.1416 \times \overline{2.625}^2 = 5.41 \text{ square inches.}$$

Consequently, if we suppose the total weight supported by the valve, including the levers, rod, disk, &c., to be 245 lbs., that weight, when the valve is shut, will represent a pressure per square inch of

$$\frac{245}{4.91} = 50 \text{ lbs.}$$

and when the valve is raised, that same weight will only represent a pressure of

$$\frac{245}{5.41} = 45.27 \text{ lbs.;}$$

by which we see that the same weight marked by the balance corresponds to very different pressures of steam, when the valve is shut or when it is raised.

Continuing, in the case of a blowing-valve, to calculate upon what is called the diameter of the valve, that is to say, on its inferior diameter, an error will thus be committed of 5 lbs. pressure per inch, which error might be still greater if the raising of the valve should happen to be more considerable. Moreover, as there is no practical means by which to learn by how much the diameter of the valve is augmented by the raising, the consequence will be that the mode of calculation explained here above, even with the corrections we have made, will apply exactly to those cases where the valve just begins to be raised, or lets scarcely any steam escape; but the greater the raising, the more the calculated amount will surpass the real pressure. We shall see hereafter examples of this.

But still this is not all. If the pressure of the steam in the boiler must be deduced from measurements taken on the engine, it must also be observed that it frequently happens, in order to make the construction more easy, that the mitre of the valve is made to join the sides of its seat only within a certain breadth, as may be seen in fig. 21. The consequence is, that the surface *ab*, or the inferior part of the valve, which has been measured, is not the surface upon which the pressure is divided. The real diameter in this case is *cd*. If therefore there be between *ab* and *cd* a difference, for instance, of one-eighth of an inch, this difference may produce, as well as in the case of the raising of the valve, a difference of 4 to 5 lbs. in the pressure. Mistakes may be avoided in that respect, by measuring not only the inferior diameter of the valve, but also the diameter of its seat. There still, however, remains the blowing of the valve, the exact appreciation of which escapes all manner of calculation.

The mercurial gauge, which we are going to describe, is the means of avoiding both causes of error; but that instrument is expensive, and as yet so scarce, that in all the factories and on all the railways, except the Liverpool one, there is at present no other mode of ascertaining the pressure than those explained above.

ARTICLE II.

OF THE MERCURIAL STEAM-GAUGE.

SECTION 1.—*Construction and use of the Mercurial Steam-Gauge.*

The calculations we have made may be sufficiently exact for a great number of cases. Still they present some degree of complication that makes them inconvenient; besides, they cannot be made without measuring and weighing different parts of the engine, which operations require time and care, and can only take place when the engine is at rest. We may therefore easily conceive the great utility of an instrument which at first sight, and by its bare inspection, will give the exact measure of the pressure of the steam. By means of such an instrument, all cases, even those of the raised valve, present no longer any difficulty, and the necessity of calculation itself may be dispensed with. The only thing required is, the possibility of submitting the engine to the proof.

The instrument used with that view is, the mercurial steam-gauge, constructed on the same principle as the common barometer. M *bm* (fig. 18) is a tube containing mercury, which ought not to rise above the two points M and *m*. FG. is the water reservoir. It must not contain water above the cock E, the use of which is to get rid of the surplus of water that may have been produced by condensation on some former experiment. R is an opening closed by a cock, and through which mercury or water may, when wanted, be introduced into the instrument. Lastly, C is an ajutage on which a tube is screwed, the other end of which reaches the boiler of the engine. This tube is flexible, and usually made of tin; it forms the communication of the mer-

curial gauge with the engine. At the point where it reaches the engine, it is screwed on an ajutage fixed to the boiler, and kept close by a cock.

To prepare the instrument for use, an additional quantity of mercury is poured into it by the aperture R, in order to be sure that the instrument contains mercury at least to the height M*m*. After this the screw-bolt M is unscrewed, so that if there happen to be too much mercury it may run off. When this is done the screw-bolt is replaced, and an additional quantity of water is also poured through R into the reservoir FG, and, should there be too much, it also runs off through the cock E. Then the instrument is put in communication with the boiler. The steam, arriving through the tube C in the upper part of the reservoir FG, presses on the water by virtue of its elastic force; it consequently presses the mercury down in the branch M*b*, and makes it to rise in the branch *mb* which is open at the top, until the weight of the mercury, thus raised, is equal to the pressure of the steam issuing from the boiler. A float borne on the surface of the mercury, at the point *m*, rises in proportion as that surface rises in the tube; and an index suspended to a thread which passes over a communication-pulley *p*, falls between the two tubes in proportion as the mercury rises in the branch *bm*, and shows upon a graduated scale the variations that occur in the level of the mercury in the different experiments. Supposing the length of the instrument from M to *b* be 6½ feet, or 78 inches, the ascending column may, if necessary, contain 156 inches of mercury; and as a column of 156 inches of mercury with a basis of 1 square inch weighs about 80 lbs., such a column may serve to measure an effective pressure amounting to 80 lbs. per square inch.

The reservoir FG is a cylinder 3 inches in diameter and 6 inches high. The use of the water it contains is to keep the branch M*b* constantly full of water, in proportion as the mercury descends in that branch. This is the reason why that reservoir is a great deal larger than the tube, and its

capacity is calculated so as to be able, in case of need, to fill the whole branch. If this precaution were to be omitted, the water formed by condensation in the instrument during the experiment would fall in the tube, which being very narrow, having, for instance, no more than one-half square inch area, the water would immediately rise in it to a considerable height, and cause by that means a surplus of pressure which would make the result false. But by means of the reservoir FG, the condensation-water, in proportion as it is formed, is divided over a surface of 7 square inches, on which, consequently, it produces an imperceptible difference in height. As it is known that the pressure of the water on the unit of surface depends solely on its height, the consequence of this arrangement of the instrument is, that the surplus of the pressure caused by the condensed steam is so small, that it may be neglected without any inaccuracy.

To graduate the scale of the instrument, we may begin by marking first the point zero. For this, the mercury and the water being poured in, as said above, the two branches must be left to communicate freely with the atmosphere, and the point where the index stops will be the point sought, for that is the position which the float naturally takes when the branch M*b* bears no more than the atmospheric pressure. If the two branches of the bent tube were to contain nothing but mercury, it is clear that the point corresponding to zero in the rising branch would be at *m*, as the mercury would in that case stand on a level in the two branches. Instead of that, the mercury in the branch M supports a certain weight of water, that is to say, the weight of the column EM; it will consequently tend to descend in that branch and to rise in the other. However, if the float is made to weigh as much as the column of water, the level will remain the same as if there were only mercury in both the branches.

The other extreme point of the scale must afterwards be marked. Let ϖ be the pressure we want to equilibrate;

supposing the equilibrium established, let x be the height at which, by virtue of that same pressure ϖ, the mercury will stand above its natural level in the branch m. The mercury having risen in the branch m to the height x, it must have fallen by an equal quantity in the other branch; for the mercury added on the one side can only proceed from what has been taken off on the other. The mercury in the branch M will therefore at the same time be at the point x', and the whole part of that branch from the point x' to the point M will be filled by the water from the reservoir. If through the point x' we draw a horizontal plane, the mercury which is under that plane will equilibrate itself in the two branches; we have therefore nothing to do with it, and need only consider the conditions of equilibrium for those parts which are above the plane in the two branches. Now, we have on the one side the pressure ϖ more the weight of a column of water high $Mx' = x$; and on the other side, we have a column of mercury high $2x$ more the weight of the atmosphere. P being the weight of the column of mercury, P′ that of the column of water, and ρ that of the atmosphere, we shall have, there being an equilibrium

$$\rho + P = P' + \varpi, \text{ or, } P = P' + (\varpi - \rho.)$$

$(\varpi - \rho,)$ which is the surplus of the real pressure of the steam over the atmospheric pressure, is called the *effective* pressure; and in all high pressure steam-engines it is this which is to be considered. The column of mercury, the weight of which we have expressed by P, having for its basis the basis of the tube which we shall express by b, and for its height the height $2x$, its volume will be $2bx$; δ representing the density of the mercury, $2\delta bx$ will be the mass of the whole column, and g expressing the accelerating force of gravitation, $2g\delta bx$ will be weight; that is to say, that we shall have

$$P = 2g\delta bx.$$

By the same reason δ' being the density of the water, the weight P′ of the column of water will be expressed by

$g\delta'bx$, its basis being also b, and its height $Mx' = x$. But the density of the water being expressed by 1, that of the mercury is expressed by 13.568; thus we have

$$\frac{\delta'}{\delta} = \frac{1}{13.568} \text{ or } \delta' = \frac{\delta}{13.568},$$

and consequently

$$P' = \frac{g\delta bx}{13.568}.$$

On the other side, the effective pressure ($\varpi - \rho$,) in whatever manner it be expressed, may be replaced by the weight of a column of mercury, that would produce the same pressure on the basis b. If then h be the height of that column, which it is easy to calculate, we shall have

$$\varpi - \rho = g\delta bh\,;$$

and the equation of equilibrium will thus be

$$2g\delta bx = \frac{g\delta bx}{13.568} + g\delta bh,$$

or

$$x\left(2 - \frac{1}{13.568}\right) = h$$

This equation gives

$$x = h \times \frac{13.568}{26.136} = h \times 0.51913.$$

The height h of a column of mercury, which may represent a given pressure, is easily found; for we know that a column of mercury, one inch high, presses on its basis at the rate of 0.4948 lb. per square inch. The height of any other column may thus be proportionably calculated. If, for instance, we wish it to represent a pressure of 70 lbs., its height will be found by the following proportion:

$$\overset{\text{lb.}}{0.4948} : \overset{\text{in.}}{1} :: \overset{\text{lbs.}}{70} : h = \frac{70}{0.4948} \times \overset{\text{in.}}{1} = \overset{\text{in.}}{141.47};$$

so that this value of h, x will be

$$x = 141.47 \text{ in.} \times 0.51913 = 6 \text{ ft. } 1\tfrac{1}{2} \text{ in.};$$

that is to say, that to correspond to an effective pressure of 70 lbs., the height of the mercury must be 6 feet $1\frac{1}{2}$ inches.

The same calculation is applicable to any intermediate point that may be sought, but it would be unnecessary trouble; for, knowing the point corresponding to zero, and that which corresponds to the *maximum* pressure of the instrument, we have only to divide the interval into equal parts, and the scale will be suitably graduated, having seen that the general value of x depends solely on the corresponding value of h, and is proportional to it.

This mercurial gauge being once constructed and graduated, whenever any doubt may be entertained in regard to the pressure of an engine, nothing more is necessary than to bring it under the instrument, and by that means the pressure may be ascertained, in whatever state the valve may be at the time, whether blowing or not.

Section 2.—*Of the pressure of the Steam in Locomotive Engines while travelling.*

When we make use of the mercurial gauge to discover the pressure during an experiment, attention must be given to a circumstance we are going to describe. If, the valve once regulated, the engine were to keep an equal pressure of steam during its whole journey, nothing more would be wanting than to try it once for all before starting. Having fixed the valve at the point at which we wish to work, the engine might be brought under the instrument; and the pressure being determined that corresponds to that point, provided no other alteration be made to the spring-balance of the valve, the pressure of the engine for every instant of the journey would be known.

It is thus that many persons calculate, whether or not use has been made of the mercurial gauge. When they have found that an engine lifts up its valve exactly at 50 lbs. effective pressure per square inch, that very moment the valve is considered as giving a free egress to the steam, and it is concluded thence that the steam will never rise above 50 lbs.

unless the valve undergoes an alteration. Experience, however, proves that this reasoning is false.

If we observe a locomotive engine with some attention, we shall very soon see that nothing is more variable than the pressure of steam in its boiler, although the valve has undergone no alteration. If the engine runs rapidly with a moderate train, and comes to a slight inclination of the road, however small that inclination may be, it immediately produces a considerable increase of traction, because the gravity of the whole mass on the inclined plane becomes an additional resistance for the engine; and the effect of this increase of traction will be so much the more perceptible on the engine, the less the resistance was which the train offered when on the level parts of the road. It is thus that a load of one ton, which on a level road requires a traction of 8 lbs. only, presents nearly four times as much if it has to ascend an acclivity of $\frac{1}{100}$, the gravity of one ton or 22.40 lbs. on that inclination being $\frac{2240}{100} = 22.40$ lbs. The consequence of that sudden increase of resistance is therefore that the engine, as soon as it arrives at the foot of the inclined plane, must diminish considerably its velocity. Supposing that in its preceding course it spent 480 cylinders of steam per minute, and in consequence of the accidental obstacle it must overcome, it is obliged to reduce its velocity to one-third of what it was before, it will evidently spend no more than 160 cylinders per minute; nevertheless, the fire violently excited by the preceding course will continue to generate the same quantity. That steam, it is true, will be spent at a greater pressure; but experience shows that the surplus of pressure does not balance what is generated too much. The valve will therefore begin to emit an enormous quantity of superfluous steam, which in order to escape will raise the valve; but if we observe that the valve cannot rise without pressing on the spring, and consequently without augmenting the tension of the spring, we will find that the steam can only escape by increasing its pressure; and, in fact, the pressure will immediately rise on the balance several pounds

per square inch, in proportion to the violence of the fire and the construction of the engine. How great then is the error committed by continuing to calculate the effective pressure at 50 lbs., because we suppose that the valve giving way at that point cannot suffer the steam to rise above it.

When the steam in escaping, raises the valve to a given height, the greater the balance-lever is, the more the index will be displaced on the scale, and, consequently, the greater will be the increase of tension of the spring; thus, in engines with a long lever, the augmentation of the pressure will be, *cæteris paribus*, more considerable than in those where the lever is shorter.

We shall soon see that the Atlas engine, which has a short lever, with a valve of 2½ inches diameter, is able, while overcoming difficult obstacles, to raise its pressure from 53 lbs. to 56 lbs.; and that the Fury engine, which has a long lever, with a valve of 3 inches in diameter, is able, in the same circumstances, to raise its pressure from 53 lbs. to 62½ lbs. These variations in the pressure depend, in each engine, in the first place, on the augmentation of the resistance created by the obstacle or the diminution of the speed; and, in the second place, on the dimensions of the valves, levers, and balances, and the evaporting power, that is to say, the quantity of steam generated by the engine.

This increase of pressure in locomotive engines, when they meet obstacles that compel them to diminish their velocity, gives the engines with long valve-levers considerable advantage over those with short levers, whenever it is necessary to ascend an inclined plane. This advantage, it is true, is only gained by submitting the engine to a higher pressure, and might also be acquired with short lever engines by lowering the screw of the spring-balance, so as to increase the pressure in the boiler in the same proportion; but the fact itself would evidently seem the proof of a superior working, and would even be inexplicable, were we to look upon the pressure as never passing 50 lbs.

The variations in the pressure which we have just men-

tioned, take place while the engine is travelling, that is to say, while it is separated from the mercurial gauge. Therefore, if an engine has been working in a given circumstance, or with a known load, and that we want to ascertain at what pressure it was then working, we must write down exactly, during the experiment, the degrees successively inscribed on the balance; then, when the engine has left off working, we bring it under the mercurial gauge, and by animating the fire sufficiently to make the balance repass through all the same degrees through which it rose during the work, and by observing at the same time the mercurial gauge, we find for each of those degrees the corresponding pressure. That is the means we employed in our experiments.

We brought successively under the instrument all the engines we had made use of, and for each of them, as they all differ in some point from one another, we determined the corresponding degrees of the mercurial gauge with the divisions of the spring-balance.

Section 3.—*Experiments on the Pressure of Steam in the Locomotive Engines.*

As those experiments serve to illustrate the foregoing principles, as they give the amount of the effect produced by the mitre and the additional parts of the valves, and as they, besides, are the foundation of some of the calculations we shall make on the engines, we shall here give an account of some of them.

I. Atlas; valve 2½ inches in diameter; mitre 2¾ inches, cut with a slant in the middle of the breadth of the valve, as may be seen in fig. 22; levers 3 inches and 15 inches, or in the proportion of 1 to 5; second safety valve, similar to the first, but fixed at too high a pressure to blow in any of the experiments.

The engine being brought to the mercurial gauge on the 15th July, 31st July, and 6th August, 1834, gave the corresponding degrees as follows:

Degrees of the balance,		Corresponding pressure per square inch, by the mercurial gauge. lbs.
No. I.	0	4
	10	15.25
	11	15.50
	20	25.50
	20.25	25.75
	20.75	26.25
	22.50	27.50
No. II.	20.25	24.75
	20.50	25.25
	22	25.75
	23	26.25
	23.75	27
	25	28.25
	30	33.50
	30.25	34.50
	30.50	35
	33	37.50
	33.25	38
No. III.	51.25	54
	51.50	54.50
	51.75	55
	52	55
	52.50	55.50

In the first series of those experiments the degrees of the balance were taken with the valve resting on its seat, at least as much as possible, that is to say, the valve emitting scarcely any steam. To obtain this, the engine was brought to the gauge when its work was finished, at the moment when the fire diminishing rapidly, the pressure also decreasedc ontinually, so that the blowing at the valve became gradually less, and at last ceased almost completely. In portion as the pressure indicated by the mercurial gauge was diminished, the screw of the balance was loosened, in order that it might continue to show the inferior pressures that were produced.

The degree corresponding to zero on the balance, could

not be taken exactly; the balance having already fallen a little below zero when the index marked 4 lbs.

In the second series of experiments the engine was, on the contrary, taken at the moment when the screw of the spring-balance being loosened on purpose, the boiler contained steam at 20 lbs. pressure only. By forcing the fire and tightening by degrees the screw of the balance, the above marked degrees were produced, and the corresponding numbers of the steam-gauge inscribed. We have seen, that in the first series all the degrees were taken with the valve resting on its seat. Here, on the contrary, the pressure, augmenting rapidly in the boiler, raised continually the valve, so that all the degrees were taken with a blowing-valve. However, as the screw of the balance was tightened in proportion as the pressure increased, the blowing was never very considerable, and scarcely ever showed above 1 or 2 lbs. on the spring-balance.

In the third series, the engine was in its usual working state; that is to say, the spring-balance marking 50 lbs. when the valve was shut by pressing upon the lever with the hand, and the valve rising beyond that point by the blowing of the steam, as far as the force of the steam was able to push it. As the screw was not tightened in proportion as the pressure augmented, the valve in this last case was raised much higher than in the preceding one.

By examining the first series, we see that, in those experiments, the pressure by the mercurial gauge is equal to the pressure marked by the spring-balance, with an addition of 5 lbs.

In the second series, we have only 4 lbs. to add to the degrees of the balance.

And in the third series, only 3 lbs.

Those differences are easily explained by referring to the preceding principles.

The valve-lever of this engine, when weighed at the place of the valve, as explained above, gave 7½ lbs.; the disk of the valve weighed 10¼ ounces; which makes for those two

objects together 8.14 lbs. weight, directly applied on the valve.

Besides, the total weight of the balance was 4 lbs., and turned upside down it marked half a pound, which gives for the weight of the rod and spring

$$\frac{4 + 1.5}{2} = 2.75 \text{ lbs.}$$

This weight of 2.75 lbs., acting at the end of the lever, must be multiplied by the length of the lever. So that the whole addition to be made to the tension marked by the spring, is

$2.75 \times 5 = 13.75$, effect of the rod and spring at the end of the lever.

8.14, weight of the lever and disk of the valve.

Sum 21.89

And as the diameter of the valve is $2\frac{1}{2}$ inches, which gives a surface of 4.91 square inches, those 21.89 lbs. divided per unit of surface or square inch, give

$$\frac{21.89}{4.91} = 4.46 \text{ lbs.}$$

So that the real pressure surpasses by 4 or 5 lbs. that which results from the spring of the balance.

This result applies to the valve resting on its seat, that is to say, in taking its diameter at $2\frac{1}{2}$ inches, which gives us for its surface in square inches, and consequently for divisor, 4.91; but as, by the effect of the blowing, the effective area of the valve is augmented, we must not be surprised, if, by a moderate blowing, this addition of 5 lbs. be reduced to 4 lbs., and even to 3 lbs. for a valve that blows violently. If, for instance, the calculation is applied to a pressure of 52 lbs. marked at the balance, we shall have

$(52 + 2.75) \times 5 = 273.75$ effect of the weight suspended at the end of the lever, including the rod and spring.

8.14 lever and valve.

281.89 total pressure.

Which, divided by 4.91 square inches, gives for each 57.41 lbs.

But in reality the corresponding point of the mercurial gauge is only 55 lbs., the blowing must therefore have augmented the real area of the valve to 5.13 square inches instead of 4.91, that is to say, must have brought its real diameter to 2.55 inches, instead of 2.50 inches.

So it is an addition of $\frac{5}{100}$ of an inch to the diameter of a valve of 2.50 inches, that has been sufficient to produce the difference of $2\frac{1}{2}$ lbs. we observe here. That is the effect of the blowing of the valve, which as we see is considerable; and it can only be known by the mercurial gauge, and not by any measures taken on the engine itself.

II. Vesta; valve $2\frac{1}{2}$ inches diameter; lever 3 inches and 36 inches, or in the proportion of 1 to 12. Second valve of the same diameter as the first, with a lever of $2\frac{1}{2}$ inches and 15 inches, or in the proportion of 1 to 6, marking 50 on the balance, and giving issue to the steam at the same time as the first, but so difficult to move, that 5 lbs. more by the mercurial gauge causes no motion in it. This engine brought to the mercurial steam-gauge on July 28, and August 5, 1834, in the same manner as the *Atlas*, gave the following results:—

	Degrees of the spring-balance.	Corresponding pressure per square inch, by the mercurial gauge.
	lbs.	lbs.
No. I.	8.50	24
	9	24.50
	9.50	26
	10	27
	10.25	28
	10.50	29
	10.75	30
	12	31.50
	12.25	32
	12.50	33
	12.75	34
	13.25	35

Degrees of the spring-balance.	Corresponding pressure per square inch, by the mercurial gauge.
lbs.	lbs.
13.50	36
13.75	37
14	38
No. II. 20 starting point of the vale	
21	50
21.25	51
21.50	52
22	53.25
22.25	54
22.50	55

The experiments of the first series were made as much as possible with the valve resting on its seat; that is to say, that the screw of the spring-balance was tightened in proportion as the pressure augmented, so that there was scarcely any blowing.

For those of the second series, the engine was brought to the mercurial gauge in its usual working state, with the spring-balance at 20, when the lever is pressed upon to shut the valve, and the degrees observed are those that result from the blowing of the steam beyond that point; that is to say, that those degrees are taken with a valve rising from degree 20.

The valve lever of this engine being divided in the proportion of 1 to 12, every weight inscribed on the spring-balance produces on the valve a pressure 12 times as great. The surface of the valve is 4.91 square inches. Multiplying therefore the degrees of the balance by 12, and dividing the produce by 4.91, the pressure resulting from the spring, considered by itself, will be obtained. That calculation is generally considered sufficient.

If the results thus obtained be compared with the corresponding degrees of the mercurial gauge in the first series of experiments, it will be found that those results are always below the real pressure by 3 lbs. or 4 lbs.; this must there-

fore be the effect of the weight of the additional parts that we are considering.

In fact, the lever of this engine, reduced on purpose by the constructor, weighs 1.5 lbs. at the place of the valve. The disk of the valve weighs 10 ounces. The balance is not placed in its usual position; it is turned upside down, so that the lever, instead of supporting the rod of the balance, bears only its foot. The weight of this foot is 0.25 lbs., for the whole balance weighs 2 lbs., and when suspended with the rod downwards it marks 15 lbs., which is the surplus of the weight of the rod over the weight of the foot; wherefrom results that the weight of the foot is, as has been said, 0.25.

So that the addition owing to these different objects is

	lbs.
Weight of the lever and disk of the valve - -	15.60
Effect of the foot suspended to the lever 0.25 lb. × 12	3.00
Sum -	18.60

This additional weight divided over each square inch of the surface of the valve makes 3.8 lbs., so that the calculation in the case of the valve resting on its seat is verified.

As for the cases of a blowing-valve, or those of the second series, the fact shows that the real pressures are less than they would be with a valve resting on its seat by 4 lbs. or 5 lbs., no other means existing of discoveriug that difference than by the mercurial gauge; so that if we had calculated the pressure in this case in the same way as in those of a valve resting on its seat, that is to say, by dividing the whole weight over a surface of 4.91 inches, or a valve of 2.50 inches diameter, we would have reckoned 4 lbs. too much in each case. It happens here that when the valve is considerably raised, the reduction, owing to the blowing, compensates at last for the addition required by the weight of the lever, disk, and balance-rod.

These examples prove how faulty would be any calculation of power or effect of engines, the real pressure of which

had not been determined by manometrical processes; and it has been already observed, that of all the railways at present in activity, the Manchester and Liverpool Railway is the only one where a mercurial steam-gauge is to be found.

III. Firefly; valve 2.50 inches in diameter; mitre 3 inches; levers 3 inches and 36 inches. This engine gave on the 2d of August, 1834:

Degrees of the balance.		Corresponding pressure per square inch, by the mercurial gauge.
lbs.		lbs.
17	starting point of the valve.	
17	- - - - -	50
20	- - - - -	51

We see that, for this engine, the addition to be made to the pressure marked by the spring-balance is 8.5 lbs. per square inch for lever, disk, and balance; and that in the cases of a blowing valve, the reduction produced by the mitre may amount to 6 lbs., this mitre being really considerable.

IV. Leeds; valve 3 inches; mitre 3.125 inches lever; 3 inches and 36 inches; second valve screwed at too high a pressure to let any steam escape during the experiments. The engine gave, on the 28th of July, and 6th of August, 1834:

	Degrees of the balance.		Corresponding pressure per square inch, by the mercurial gauge.
	lbs.		lbs.
No. I.	28	starting point of the valve.	
	29.50	- - - - -	50
	29.75	- - - - -	51
	30	- - - - -	51.5
	30.50	- - - - -	52
	31	- - - - -	53

Degrees of the balance.		Corresponding pressure per square inch, by the mercurial gauge.
	lbs.	lbs.
No. II.	31 starting point of the valve.	
	32	54
	33	55
	34	56
	36	57.5
No. III.	32 starting point of the valve.	
	34	60

V. Vulcan; with valves and levers exactly similar to those of the preceding engine; second valve different, but also fixed too high to give any sign during the experiments: gave on the 28th of July, 1834:

Degrees of the balance.	Corresponding pressure per square inch, by the mercurial gauge.
lbs.	lbs.
31 starting point of the valve.	
35	56.5

VI. Fury; with valves and levers exactly similar to those of the preceding engine; second valve different, but also fixed too high to give issue to the steam during the experiments: gave on the 6th of August, 24th and 25th of July, 1834:

Degrees of the balance.		Corresponding pressure per square inch, by the mercurial gauge.
	lbs.	lbs.
No. I.	31 starting point of the valve.	
	33.50	56.50
	33.75	57.50
	34	58
	36	62.50
No. II.	32 starting point of the valve.	
	36	67

In the first series of experiments with the LEEDS, the blowing of the valve was from the degree 28 to the degree 31 of the spring balance. In the second series of the same engine it was from 31 to 36, which is considerable. In the third series it was less, say 32 to 34. It is therefore in that third series that we find the smallest reducing effect of the mitre.

The experiment of the VULCAN is the common working state of the engine.

In the experiments of the FURY, there are two different effects of the mitre as well as in those of the LEEDS.

In consequence of the weight of the levers and balance-rods of these three engines, the addition to be made to the effect of the tension of the spring is 7 lbs. per square inch; but, on the one hand, the blowing, and on the other, the circumstance of the seat of the valve not fitting the valve entirely, produce the reductions we find here. That circumstance explains the anomalies those experiments apparently present.

ARTICLE III.

OF A NEW SPRING-BALANCE AND MANOMETER.

SECTION 1.—*Of a proposed Modification to common Valves.*

All the foregoing calculations are as many proofs of the difficulty of acquiring a knowledge of the real pressure of the steam by the inspection of the spring-balances, so as they are at present constructed, and the mistakes that must necessarily occur, whenever we have no mercurial gauge at our disposal.

These difficulties might evidently be avoided by adopting a new disposition for the valve, of which, during our stay in Liverpool in the month of July, 1834, we left a drawing with one of the directors of the railway company.

The fulcrum of the lever must be placed between the valve and the spring-balance, as in fig. 17, and the balance suspended by its rod as in common weighing; besides, the long branch of the lever must equilibrate round the fulcrum C, with the short branch more the disk of the valve, which can be easily effected by augmenting a little the breadth of the shortest lever, or by putting some additional mass of metal under the valve. Lastly, the proportion between the two branches of the lever, must be the same as that of the area of the valve to the unit of surface, and the seat of the valve must be fitted to it exactly.

By means of this simple disposition, it is clear that the degree inscribed on the balance will show immediately, and without any calculation, the effective pressure which takes place in the boiler. In fact, 1. The spring-balance being placed in its usual situation, in which the weight of the foot P is taken into account, no addition will be required for the weight either of the foot or the rod. 2. The two parts of the lever equilibrating with each other, there will be no addition required for the weight of the lever or the valve. Lastly, the branches of the lever, bearing to each other the proportion of the area of the valve to the unit, any number inscribed on the balance will represent an equal pressure on the unit of surface of the valve.

Thus this valve will dispense with all calculation, and will show immediately written on the balance, the real pressure per square inch. It will exactly answer the conditions required of a valve, which is intended only to limit the pressure; that is to say, that if we fix it at 50, we may be certain, without any calculation or consideration whatever, that the steam will raise it precisely at 50 lbs. pressure per square inch. This is all that is commonly required for the business of a railway, where the proprietors only wish, through pru-

dential motives, that the engine may be regulated according to a determined pressure.

In case of theoretical experiments on certain circumstances of the motion of the engines, a deduction must still be made for the effect of the mitre in the blowing; and in these cases, recourse must still be had to the mercurial gauge: but we are also going now to propose a portable instrument, capable of being used instead of it; and which, besides, does not require the use of the above-described valve.

SECTION 2.—*Of a new portable Manometer, calculated to replace the Mercurial Gauge.*

We have observed, that at present when we wish to know at what pressure an engine was working in a given circumstance, it is necessary, after the experiment, to bring it to the mercurial gauge, in order to know the pressure that corresponded with the different degrees of the spring-balance, observed during the work.

This second experiment, which must succeed the first, is of itself an inconvenience. Besides it is necessary, in seeking the pressures, to replace all things precisely in the state in which they were during the trial of the engine. In fact, we have seen that a valve fixed at 32 lbs. as starting-point, and blowing at 36, may represent 67 lbs. pressure, whilst that same valve having its starting-point at 31 lbs., the same degree of 36 may only correspond with 62 lbs. The second valve must also have been observed during the work, and be replaced precisely at the same point; for if it be loosened, it will give issue to a certain quantity of steam, which else would necessarily have been forced to escape through the first, and thus have augmented the pressure. Lastly, the engine-men have an interest in concealing the true pressure of the engines, for fear of their being obliged to reduce it. They calculate that it would diminish the speed of their course, and thus keep them longer on the road. In consequence, they not only loosen, secretly, the second valve, and

raise from time to time the lever, in order to augment the effect of the mitre with which they are very well acquainted, but they also sometimes slip a metal plate, under the pin which presses on the valve, in hopes of deceiving in regard to the real degree of the balance.

The precautions necessary to be taken in seeking the pressure, make that research more fastidious than it would seem at first sight, when one has a mercurial gauge at one's disposal. To this must be added, that the steam necessarily cools in the long passage from the engine to the instrument. It is forced to follow a metallic tube 8 to 10 feet long by half an inch in diameter, and must consequently arrive on the mercury with a less degree of pressure than in the boiler.

These difficulties proceed evidently from the impossibility of fastening the mercurial gauge to the engine; for if that could be done, one might read on it the pressure immediately during the work, and no second experiment would be necessary.

We are therefore of opinion, that that instrument might be advantageously replaced by the following one:—

The engine having its two safety-valves as usual, and constructed in any way, R (fig. 19) is a cock fixed on the boiler, and susceptible, when wanted, of giving issue to the steam it contains. The orifice of the cock bears on the outside the thread of a screw, in order that the instrument may be screwed to it. The upper part of the figure represents the instrument itself. It presents a tube which is to be joined to the ajutage of the cock R. These two pieces being brought next to each other, and bearing each of them the thread of a screw on the outside, a moveable screw E, unites them firmly to each other, as long as the experiment lasts, as may be seen on the figure. Then turning the cock R, the steam will have access into the tube of the instrument.

Besides, A is a valve, the area of which is one square inch, or any other unit of surface, according to that which

one wishes to employ for measuring the pressure. This valve, while tending to rise, acts against a lever AC, the opposite end of which is kept back by the pressure of a spiral spring, forming a common spring-balance. The two branches of this lever are equal, and their reciprocal weight, including the disk of the valve for the corresponding side, equilibrate exactly round the fulcrum C. Lastly, the point S is fastened by a screw to some part of the boiler, in order to give solidity to the whole.

The instrument being thus fastened to the engine, and the cock opened, the steam will act against the valve, and the consequence of the dispositions we have explained will be, that the inspection of the balance will immediately give the real pressure per square inch. In fact, by the position of the balance, there is no addition to be made for the weight of the rod or foot; the equilibrium of the lever renders also unnecessary any correction for its weight; and lastly, the two common valves of the engine giving issue to the surplus of the steam, the valve A will never blow. The screw may thus be lowered, until the balance equilibrates exactly the pressure of the the steam, by which means no effect of mitre will complicate or falsify the result.

The facility with which the real pressure may be found, without being obliged to make purposely a second experiment; the accurateness of the observation, the steam not having a long passage to make before it arrives at the instrument; the advantage the instrument presents of being carried with the engine, and, when necessary, fastened to any other engine; lastly, its low price, whereas the mercurial steam-gauge is very expensive: all those reasons combine to persuade us that this manometer may be of some use. With it, all the difficulties we met with in our experiments would immediately have disappeared. It may, besides, also serve to determine the pressure, as well in locomotive engines, as in any other high or low-pressure steam-engines.

The accurateness of the instrument may easily be verified once for all; 1, by measuring the valve when separated from

the engine; 2, by examining whether the lever equilibrates of itself on the fulcrum; 3, by taking the balance off and suspending known weights to it, to see whether they coincide with the divisions.

Section 3.—*Comparative Table of the different Modes of expressing the Pressure of Steam.*

To complete what has been said in this article, and to facilitate to the reader the converting of the different measures of pressure, which we shall be obliged to make use of in the course of our work, we subjoin here a table of the different modes of expressing the pressure of the steam. We have calculated it by half atmospheres, but the intermediate degrees may be easily filled up.

COMPARATIVE TABLE OF THE DIFFERENT MODES OF EXPRESSING THE PRESSURE OF THE STEAM.

Total pressure of the steam.				Surplus of that force over the atmospheric pressure, or effective pressure.			
In atmospheres.	In inches of mercury.	In lbs. per square inch.	In lbs. per square foot.	In atmospheres.	In inches of mercury.	In lbs. per square inch.	In lbs. per square foot.
1	30	14.7	2,117	...	...	...	...
1.5	45	22	3,175	0.5	15	7.3	1,058
2	60	29.4	4,234	1	30	14.7	2,117
2.5	75	36.7	5,292	1.5	45	22	3,175
3	90	44.1	6,350	2	60	29.4	4,234
3.5	105	51.4	7,409	2.5	75	36.7	5,292
4	120	58.8	8,467	3	90	44.1	6,350
4.5	135	66.1	9,526	3.5	105	51.4	7,409
5	150	73.5	10,584	4	120	58.8	8,467
5.5	165	80.8	11,642	4.5	135	66.1	9,526
6	180	88.2	12,701	5	150	73.5	10,584

CHAPTER III.

OF THE RESISTANCE OF CARRIAGES MOVED ON RAILWAYS.

SECTION 1.—*Necessity of making farther researches on that subject.*

FROM the description we have given of the engine, we see that the steam, by acting on the pistons, communicates to the wheels a rotatory motion, which must necessarily make the engine advance, provided the train that follows, does not oppose a greater resistance than the force of which the engine disposes.

The first point therefore which must be considered concerning the motion of locomotive engines is the resistance opposed by the trains they draw.

Those trains consist of a more or less considerable number of carriages called wagons, upon which the goods are loaded. Their resistance to the motion depends not only on their weight, but also on the state of the railway, and the more or less perfect construction of the carriages. The purpose of the establishment of a railway being to produce a perfectly hard and smooth road, on which the carriages may roll with ease, if the railway is not kept in good order, or if it does not answer the intentions for which it was established, it is clear that the resistance the train will oppose along those rails will be so much the greater. The

same will also take place if the carriages, being ill-constructed or badly repaired, have a considerable friction.

From this observation, we see that the power required to draw a given weight, a ton for instance, cannot be the same upon all railways, nor with all sorts of carriages. On perfectly smooth rails, and with a well-greased and well-constructed wagon, the draft of a ton may require only a power of 8 lbs. We mean to say, that a weight of 8 lbs. suspended at the end of a rope passing over a pulley, will, in that case be sufficient to make a loaded carriage, weighing a ton, move forward. On another railway, on the contrary, and with carriages of another construction, the same load of of a ton may require a power of 10 lbs., and perhaps more.

The old wagons, on which some experiments had been made, required a power of 10 lbs. to 12 lbs. for each ton weight of the load. Since that time, the carriages had been brought to greater perfection, and had never been submitted to any experiment made on a large scale, and in the usual working state. At the time of the introduction of the new wagons at Liverpool, one trial had been made with a single wagon, and just at the moment it was coming out of the hands of the maker. But as that wagon had been carefully oiled on purpose for the experiment, and as it had not yet encountered any shock by which the axles might have been bent, the wheels warped, or the hind wheels prevented from following exactly in the track of the fore ones; and as, moreover, the rails had been nicely swept, the result of such an experiment could scarcely be considered as a common practical result; and, in fact, the friction of the trains continued to be calculated on the Liverpool Railway at the rate of 10 lbs. per ton. These uncertain data could not be admitted in a new work on the subject.

It became therefore necessary for us to find another base for the calculations that were to be made on modern wagons. However, the occasion which gave rise to the experiments we are going to relate, occurred in the work of the locomotive engines. They pointed out themselves in a

way, the errors committed in the appreciation of the resistances they overcame. This point is worthy of notice, as it proves at the same time both the perfection of the engines, and the correctness of the calculations, to which it is possible to submit them. It inspires consequently more confidence in the other results which were obtained in the same way, and it is for that reason we mention it. Having made, during our stay at Liverpool, in 1834, a great number of experiments on the power of locomotive engines, we found that one of those experiments, made with the ATLAS, and which we shall have occasion to relate hereafter, appeared to exceed the limits of the power of that engine. The ATLAS had, on July 23, on an inclined plane at $\frac{1}{1100}$, drawn 40 wagons, weighing 190 tons, and the diameter of its cylinder was only 12 inches. According to the ideas admitted on the railway, on the resistance of the trains, this fact could only be explained, by supposing either that the proportions of the engine were not exactly what they were thought to be, or that the railway had a different inclination from what was computed, or the train a different weight from that inscribed on the weighing books. Other experiments, however, made by us with other engines, in other circumstances, and in other points of the railway, having given similar results, we were already convinced that the friction of the wagons could not exceed 8 lbs. per ton, and that the mistake lay there, unless we preferred supposing that mistakes had been made in the dimensions of all the engines, and in the levelling of all the parts of the road.

It became, therefore, necessary to ascertain the fact in a direct manner, by establishing a series of experiments for that purpose; but it was particularly satisfactory to have been led to the knowledge of the truth by the calculation, as the experiment became thus the verification of it.

SECTION 2.—*Of the Friction determined by the Dynamometer.*

The most natural means of determining the friction or resistance of the wagons, seemed to be the dynamometer, which gives directly the force of traction required to execute the motion; but as the act of drawing, either by men or any other living moter, takes place by starts, the dynamometer oscillates between very distant limits, and can give no certain result. It appeared, however, to us, that if the draft were effected by an engine, the effort of which is always equal, and the motion regulated by the mass of the train itself, the oscillation of the dynamometer would not be so great, particularly if the instrument were to be fastened to one of the last carriages, on which the pulsations of the engine have naturally much less effect.

Therefore, at the moment the LEEDS engine was setting off with a train of 12 wagons, after the whole mass had been put in motion, and while the motion continued with a uniform velocity of three or four miles an hour, the chain of the last three carriages was unhooked, and replaced by a circular spring-balance, which had been prepared for the purpose. The rod of the balance was fixed to the frame of the ninth wagon, and the three following, which were the last of the train, were fastened to the spring. The experiment took place between the milestones one and a half and two of the Liverpool Railway, on a space of ground which is a dead level.

We expected to see the index of the balance remain nearly steady; but we were disappointed. Its average position was near the point marking 100 lbs. but it underwent very great variations, that is to say, from 50 lbs. at least, to 170 lbs. at most; and even two or three times, at certain extraordinary starts of the engine, the needle ran to the end of the balance, marking 220 lbs. As, however, this case happened

only accidently, it could not be considered as an effect of the regular draft: and, indeed, after the shock which had caused this extraordinary excursion, the needle immediately returned to its usual point of 100 lbs., and began again its oscillation between 50 lbs. and 170 lbs. After having, to no purpose, waited to see whether the motion would become more regular, we concluded that the experiment was not susceptible of a greater degree of precision.

The variations of the needle between 50 lbs. and 170 lbs., gives an average of 110 lbs.

The three wagons weighed together 14.27 tons.

So the experiment gave $\frac{110}{14.27}$ or 7.70 lbs. resistance per ton.

It is important to remark, for what will be said hereafter, that this experiment was free from the direct resistance of the air; for these three wagons being the last of the train, underwent from the air only a very inconsiderable lateral resistance, particularly as the speed was only three or four miles an hour. All the direct resistance of the atmosphere took place on the first carriage of the train, with which our experiment had nothing to do.

This approximation, as it was, might be useful, but it was thought necessary to obtain more positive results.

In consequence, a convenient place having been chosen on the Liverpool Railway, at the foot of Sutton inclined plane, and at a distance of 11½ miles from Liverpool, the level was taken in the most accurate manner, to a tenth of an inch, and the experiments commenced on the following principle:

Section 3.—*Of the friction determined by the Angle of Friction.*

Let us suppose a heavy body left to itself on an inclined plane AB (fig. 23,) and sliding without friction to the foot of the plane; let us suppose at that point another plane, being the continuation of the first, and on which the same body continues its motion.

The body will descend along the plane, by virtue of its gravity; but that force will act only partially: it will be decomposed into two others, one perpendicular to the plane, which will be destroyed by the resistance of that plane, and the other in the sense of the plane, which will have its full effect, and will be the accelerating force of the motion. If therefore g express the intensity of gravity, and θ' the angle of the plane, with a vertical line, the accelerating force of the motion will be

$$\varphi = g \cos \theta';$$

but the general expression of any accelerating force is $\varphi = \frac{\dot{v}}{\dot{t}}$, v being the velocity, and t the time; consequently

$$g \cos \theta' = \frac{\dot{v}}{\dot{t}}.$$

Besides, when we consider only an infinitely small interval of time, any motion may be regarded as uniform, which, by expressing by x the space passed over, gives

$$v = \frac{\dot{x}}{\dot{t}},$$

or

$$\dot{t} = \frac{\dot{x}}{v}.$$

Thus the equation above becomes

$$v\dot{v} = g \cos \theta' \dot{x}.$$

Making the integral, and observing that the velocity is zero at the starting point, or that $x = 0$ gives $v = 0$, we have

$$\frac{v^2}{2} = g \cos \theta' x.$$

This equation gives the velocity of the moving body in any point whatever of the first plane.

Consequently, if we express by x' the distance of the point B, from the starting point, measured along the plane, the velocity of the falling body, when arrived at that point, is

$$V^2 = 2g \cos \theta' x'.$$

This is the velocity the body has acquired, at the moment it is going to pass from the first to the second plane. This velocity being applied to it in the direction of the first plane,

would produce, in the direction of the second, only a certain velocity, resulting from the relative inclination of the two planes, if the passage from the one to the other took place abruptly. But if the passage is effected by a continued curve, we know that there will be no loss of velocity, and the body will begin its motion on the second plane with the same velocity it had in leaving the first. This will, therefore, be its velocity in beginning its descent on the second plane.

The body will, besides, continue to be impelled by gravity. θ'' being the angle of inclination of the second plane with a vertical line, the gravity will produce an accelerating force

$$\varphi' = g \cos \theta'';$$

and by a calculation similar to the former, we will also have on that plane,

$$v^2 = 2g \cos \theta'' x + C.$$

In this equation, C is determined by the condition that $x = o$ must give for v the incipient velocity of the second motion; and as we have seen that this incipient velocity is

$$V^2 = 2g \cos \theta' x',$$

it follows that

$$C = 2g \cos \theta' x'.$$

Substituting that value of C, the velocity in any given point of the second plane is expressed by

$$v^2 = 2g \cos \theta'' x + 2g \cos \theta' x'.$$

Farther z' and z'' being the vertical heights gone through on each plane by the moving body, we have

$$x' \cos \theta' = z', \text{ and } x \cos \theta'' = z''.$$

Consequently the equation may be written in the following form:

$$v^2 = 2g (z' + z'';)$$

or

$$v^2 = 2gz,$$

by letting z express the vertical height of the point where the moving body is below the starting point.

This is therefore the equation of the motion, in the case of a body moving without any friction or resistance whatever. In that equation we see that we can only have $v = o$, when $z = o$; that is to say, that the body once put in motion, will not stop until it has re-ascended the second plane to the height of its starting point, that second plane being then supposed to be inclined in an opposite sense to the first.

But if the body moves with friction, experience having proved that friction does not increase with the velocity, it will act as a uniformly retarding force, contrary to the gravity along the plane. By the introduction of that new force, the accelerating forces of the motion on each of the planes will no longer be

$$g \cos \theta', \text{ and } g \cos \theta'';$$

but

$$g \cos \theta' - f, \text{ and } g \cos \theta'' - f,$$

f being the expression of the retarding force owing to the friction.

In that case the velocity in any given point m of the second plane, the distance of which to the point B is expressed by x, will consequently be

$$v^2 = 2\,(g \cos \theta'' - f)\, x + 2\,(g \cos \theta' - f)\, x'.$$

Effecting the indicated operations, and substituting z'' for $x \cos \theta''$, z' for $x' \cos \theta'$ and z for $z' + z''$, we have

$$v^2 = 2\,[gz - f\,(x' + x;)]$$

which equation gives the velocity in any point of the motion of the planes, taking the friction in consideration. In that case we see by the equation that we cannot have $v = o$, unless $z = o$, $x' = o$, $x = o$, that is to say, at the beginning of the motion; or unless we have the equation

$$g\,z - f\,(x' + x) \quad o.$$

If, therefore, a body once put in motion stops at any point, m for example, that point must fulfil the above condition, or we must have

$$gz = f\,(x' - x.)$$

If we multiply the two members of that equation by M, mass of the moving body, we shall have

$$gMz = fM\ (x + x'.)$$

The quantity g being the action of the gravity on one of the elements of the body, gM is its action on the whole of that body, or its weight, which we shall express by P. Also, f is the retarding action of the friction, as relates to a single element of the moving body. But the friction being proportional to the weight, fM is the friction when we consider the whole mass of the body. Expressing, then, that friction by F, and making those two substitutions, the equation may be written in the following form:

$$Pz = F\ (x + x'.)$$

Let us suppose then, that, having left in the beginning the moving body free on the inclined planes, it has descended to the point m, for instance, and has not gone farther; that point must necessarily fulfil the above condition, else the moving body would not have stopped there. If, therefore, we measure on the spot the quantities z, x and x', and know the weight P, the equation will contain no other unknown quantity but F; so that equation will give us its value, viz.

$$F = P\frac{z}{x + x'}.$$

Consequently, when a body of a given weight P, placed in the above-stated circumstances, stops in descending at a certain point m, *the value of the friction that stopped it, will be found by dividing the total height from which the body descended by the total distance which it travelled over.*

This determination once made, it is clear that if we were to construct an inclined plane, the height of which were z, and the length $x + x'$, and if we were to place the body on it, it would remain in equilibrium. In fact, the gravity that tends to impel the body onwards would be exactly equal to the friction that retains it.

The ratio $\frac{z}{x + x'}$, gives us, consequently, what is called the

angle of friction; and it is for that reason that we have also called by that name the principle we have explained, and which we shall make use of in the following experiments.

Section 4.—*Experiments on the Friction of Wagons.*

A series of experiments was accordingly undertaken on that principle, upon one of the inclined planes on the Liverpool and Manchester Railway.

From a point taken on Sutton inclined plane, at 50 chains from the foot of that plane, 34 distances of 10 chains or 330 feet each were measured. At each of these points a numbered pole was fixed in the ground, and the level exactly taken. The following table shows the result of the levelling operation expressed in feet and decimals of feet.

Number of the posts.	Distance from the first post in feet.	Vertical descent below the first post in feet, and decimals of feet.	
0	0	0	Starting point.
1	330	3.47	
2	660	7.07	
3	990	10.62	
4	1,320	14.36	
5	1,650	18.17	
6	1,980	21.77	
7	2,310	25.53	
8	2,640	28.98	
9	2,970	32.07	
10	3,300	34.61	Foot of the inclined plane, rather middle point of the continued curve.
11	3,630	35.06	
12	3,960	35.19	
13	4,290	35.23	
14	4,620	35.37	
15	4,950	35.71	
16	5,280	36.17	
17	5,610	36.44	
18	5,940	36.66	
19	6,270	36.80	
20	6,600	36.92	
21	6,930	37.06	

Number of of the posts.	Distance from the first post in feet.	Vertical descent below the first post in feet, and decimals of feet.
22	7,260	37.14
23	7,590	37.22
24	7,920	37.37
25	8,250	37.34
26	8,580	37.63
27	8,910	37.92
28	9,240	38.14
29	9,570	38.35
30	9,900	38.54
31	10,230	38.67
32	10,560	38.77
33	10,890	38.92
34	11,220	39.08

On the ground where the experiments took place, a little beyond the foot of the inclined plane, the wagons had to cross three junction roads, each of them necessitating the passing over three switches, as may be seen in fig. 24. This made in all nine switches, either on one side of the rails or the other. On passing each of these obstacles, the wagons received a jolt from the unevenness of the road, and their velocity was checked. The ground was consequently unfavourable for experiments, and made the friction appear rather more considerable than it really was.

The wagons used for the experiments are of the following construction. They consist of a simple platform, supported on four springs. Their wheels are three feet in diameter, and fastened to the axle-tree which turns with them. The body of the carriage rests upon the axletrees, but outside the wheels; that is to say, that the axles are prolonged through the nave, in order to support the carriage. At the bearing they are turned down to $1\frac{3}{4}$ inches in diameter. The chair is made of brass at the bearing-point. In its upper part it contains grease, continually feeding upon the axle through a hole in the chair, and the waste of which is prevented by a cover on the underside of the chair. The grease box, which

is filled every morning, is sufficient for the whole day. In the experiments, no alteration whatever was made to the usual dispositions; every thing was left as it is in the daily work, as well in regard to the wagons as to the rails. Among the wagons there are some, the extremity of the axle of which, instead of being from one end to the other of a uniform diameter of $1\frac{3}{4}$ in., is thickened near the frame of the carriage by $\frac{3}{8}$ of an inch, and is on the contrary diminished as much at the other end. Consequently, that part of the axle is composed of three cylindrical parts equal in length, and the diameters of which are, $2\frac{1}{8}$, $1\frac{3}{4}$, and $1\frac{1}{8}$ inches.

This disposition is adopted, in order to leave the mean diameter as it was at first, but to give, however, a greater strength to the point which appears to suffer the most. There are, nevertheless, but few axletrees constructed on that principle, they having been only meant as a trial, the advantage of which has not yet been confirmed by experience.

I. On July 29, 1834, five wagons taken at random, and loaded with bricks, were brought to the spot fixed for the experiments by the Sun engine. The train was followed by a sixth empty wagon. The weight of the five wagons together, accurately taken with their load, amounted to 30.65 t., and including the weight of ten persons, not weighed with them, to 31.31 t., or to 6.26 t. per carriage.

The middle of the train having been carefully placed facing the starting point on the plane, and the engine being taken away, the brakes were taken off all at once, at a given signal, and the five wagons were left to their gravity on the plane. They continued their motion till 33 ft. beyond post No. 30, having thus run a total distance of 9933 feet., with a difference of level, between the points of departure and arrival, of 38.55 ft.

By recurring to the principle laid down above, we had, in this experiment, $x + x' = 9933$ ft., $z = 38.55$., and the friction

was the $\frac{38.55}{9933}$ or $\frac{1}{258}$ of the weight. Consequently the friction of a ton was $\frac{1\ \text{t.}}{258} = \frac{2240\ \text{lbs.}}{258} = 8.69$ lbs. This friction, however, included the resistance of the air, and was augmented by the above-mentioned circumstance, of the passage of nine switches at the foot of the plane.

II. After this first experiment, 300 bricks were taken out of each of the wagons. The weight of 100 of those bricks having been carefully taken, and found to be 855 lbs.; this was, consequently, an alleviation of 2,565 lbs. 1.145 t. for each carriage. The weight of the five loaded wagons, including the same ten persons, amounted thus to 25.58 t. or 5.12 t. for the average weight of each of them.

In this state the wagons were brought back to the same starting point as at first, and left again to their gravity on the plane. They continued their motion until 84 ft. beyond the post No. 28, having gone through a total distance of 9324 ft. on a difference of level of 38.19 ft. In this second experiment the friction was $\frac{1}{244}$ of the weight, or 9.17 lbs. per ton: so the resistance per ton was less in the first case than in the second.

The wagons were then for the third time brought back to the starting point, and each of them was successively and separately left to itself on the plane, as also the empty wagon, when they gave the following results:

	Number of the wagon	Weight loaded. tons.	Distance gone through. feet.	Difference of level. feet.	Friction.	Friction per ton. lbs.
III.	No. 294.	4.65	7,326	37.16	$\frac{1}{197}$	11.36
IV.	100.	5.15	6,663	36.95	$\frac{1}{180}$	12.42
V.	196.	5.20	7,455	37.19	$\frac{1}{200}$	11.17
	111.	5.00	stopped by mistake		,,	,,
	150.	4.85	stopped by mistake		,,	,,
VI.	empty wagon 202.	1.85	6,204	36.78	$\frac{1}{169}$	13.28

The wagon, No. 100, at the moment it arrived, had one

of its axle-boxes very hot, which explains why it did not continue its motion as far as the others, though equally loaded. The empty wagon was very low, being formed only of a platform surrounded by an open railing.

According to these experiments, each of the loaded wagons, taken separately, had an average friction of 11.8 lbs. per ton; and those same five wagons, united together in a train had only a friction of 9.17 lbs. per ton. The difference in favour of a greater number of carriages was evidently owing to the resistance of the air, the effect of which only takes place on the first carriage. If the train is composed of only one wagon, that one alone must bear the whole resistance; but if it is composed of several, the resistance of the air remaining the same, is divided between all the wagons, and becomes consequently less perceptible on each of them. The same effect may be observed in the first experiment compared with the second. The number of carriages was the same in both, but the first train being more heavy, the resistance of the air was distributed between a greater number of tons.

It appeared therefore necessary, in order to complete our investigation, to make other experiments, with trains of different weights and in different circumstances. In the following experiments the wagons were no longer loaded with bricks, but with goods of different sorts, such as were furnished by the trade in the common business of the railway.

VII. The following day, July 30, a train of 19 loaded wagons was brought to the same place by the Mars engine. The 19 wagons weighed together exactly 92 tons, giving 4.84 tons for the average weight of each of them. The train was again stopped on the plane, so as to make the middle or centre of gravity of the mass exactly facing the post No. 0; and the whole was left to its gravity as in the foregoing experiment. The mass being put in motion, stopped at 168 ft.

beyond the post No. 32. So the space gone through was 10,728 ft., and the difference in level between the starting and stopping points was 38.85 ft., which made the friction equal to $\frac{1}{276}$ of the weight, or 8.11 lbs. per ton.

VIII. The same day the same experiment was made with the tender of the Jupiter engine, which stopped at 27 ft. beyond the post No. 18, and its friction was, consequently, including the resistance of the air, $\frac{1}{163}$, or 13.76 lbs. per ton. This tender is nothing but a wagon of a particular form, giving, comparatively, a considerable hold to the air, particularly when it is not much loaded. The tender of the Jupiter was then nearly empty, having only sufficient provisions to bring back to Liverpool the persons that were present at the experiment.

This as well as the preceding day's experiments were made jointly with Mr. H. Earle, one of the directors of the railway; Mr. J. Locke, engineer of the Grand Junction Railway; Mr. King, of the Liverpool Gas-works, and other persons more or less directly connected with the administration of the Company.

IX. On the 31st of July the tender of the Atlas engine, then weighing 5½ t., was left to itself from a point situated at 84 ft. below the post No. 1. It stopped at 90 ft. beyond the post No. 23, having run over a space of 7,266 ft. by 32. 88 ft. descent, which gives for the friction $\frac{1}{221}$, or 10.13 lbs. per ton.

X. The same day the train led by the same Atlas engine, composed of 14 wagons, weighing together 61.35 t., was left to its gravity on the plane from a point situated at 24 ft. above the post No. 1. Not having at our disposal a sufficient number of men, the train could not be stopped before. It ran to 15 ft. before the post No. 5; that is to say, over a space of 9579 ft., in a descent of 35.32 feet, which gives for the friction $\frac{1}{271}$, 8.26 lbs. per ton.

XI. On the 1st of August a train of 10 wagons was brought to the place of the experiments by the Vesta en-

gine. The 10 wagons weighed together 43.72 t. The tender of the engine, weighing five tons, was left attached to them, making thus together 48.72 t. for 11 carriages, or 4.43 t. per carriage. The whole was left to its gravity on the plane, and ran till 108 ft. beyond the post No. 30, being a space of 10,008 ft. on a slope of 38.58 ft., which gives for the friction $\frac{1}{259}$, or 8.64lbs.per ton.

XII. The same day 24 wagons were brought to the same place by the ATLAS engine, these 24 wagons weighing together 104.50 t., and making, with the tender of the engine, which weighed 5.50 t., 110 t. for 25 carriages, or 4.40 t. per carriage. They were left to their gravity on the plane, and did not stop until they reached 108 ft. beyond the post No. 32. They ran, consequently, over a space of 10,668 ft., with a descent of 38.82 ft., which puts the friction at $\frac{1}{275}$, or 8.15 lbs. per ton.

Lastly, complete trains, that is to say, the engine, tender, and wagons together, were brought to the trial of gravity on the plane, and gave the following results:—

XIII. On the 2nd of August the FURY engine, followed by its tender and by 17 wagons, weighing as follows: wagons 81.26 t., engine 8.20 t., tender 5.5 t., together 94.96 t., was left to its gravity on the plane. The engine and its tender being, on account of their weight, reckoned for three wagons in the position of the centre of gravity of the mass, the whole was considered as equal to 20 wagons. The train was consequently stopped so as to place facing the starting-post, the interval between the seventh and eighth wagon. The mass, being put in motion, stopped at 42 ft. beyond the post No. 34. It had run over 11,262 feet, with a descent of 39.10 ft.; which puts the friction at $\frac{1}{288}$ of the weight, or 7.78 lbs. per ton, including the engine, tender, and wagons.

The whole weight of the train, engine included, was 94.16 t. The resistance of the whole, taken at the rate of

7.78 t. as it had been found, was then 733 lbs. But the engine, submitted alone and a moment before to the experiment, had been found to have 113 lbs. friction, as we shall see below. Of these 733 lbs. there were, consequently, only 620 applicable to the wagons and tender. Their aggregate weight was 85.96 t.; consequently the resistance belonging to them was 7.21 lbs. per ton.

XIV. On the 2d of August the VULCAN engine, weighing 8.54 t., followed by a train of twenty wagons, weighing 96.30 t., and by a tender weighing 5.5 t., forming together a mass of 110.14 t., was brought to the place of the experiments. Not having been able to stop the train in time, it could only depart from a point situated at 18 ft. below the common starting-post, the engine and its tender being reckoned together for three wagons, in fixing the situation of the centre of gravity. The mass stopped at 39 ft. beyond the post No. 33. The distance ran over in 12′ 10″ was 10,911 ft. on a descent of 38.75 feet. The friction calculated over the whole was consequently $\frac{1}{282}$ of the weight, or 7.96 lbs. per ton.

The total resistance for the 108.50 t. weight of the whole train, engine included, was 863 lbs.: if from that we deduct 127 lbs. for the resistance of the engine itself, according to an experiment made immediately afterwards, and of which we shall speak below, there remains for the 100.16 t. of the train and tender 736 lbs., which make 7.35 lbs. per ton.

XV. To conclude, on August 15, the LEEDS engine, weighing 7.07 t., followed by its tender and a train of seven wagons, the aggregate weight of which, besides the engine, was 33.52 t., was also submitted to the same experiment. Starting exactly from the post No. 0, it ran till 255 ft. beyond the post No. 24. Distance 8,175 feet; descent 37.35 ft.; friction of the whole $\frac{1}{219}$, or 10.23 lbs. per ton.

The whole train weighing 40.59 t., had therefore a total resistance of 415 lbs.; and as the engine submitted alone to the experiment had been found to have 112 lbs. friction, on

those 415 lbs., there were only 303 lbs. applicable to the wagons and tender, and consequently the resistance belonging to the train was $\frac{1}{248}$, or 9.04 lbs. per ton.

SECTION 5.—*Table of the Results obtained in those Experiments on the Friction of Wagons.*

Bringing together the different experiments described hereabove we make out the following table:—

EXPERIMENTS ON THE FRICTION OF WAGONS.

Number of the experiment.	Date of the experiment.	Description of the trains.	Weight of the train.	Weight per wagon.	Distance run over.	Duration of the race.	Difference of level.	Friction.	Friction per ton.	Observations.
	1834.		Tons.	Tons.	Feet.		Feet.		lbs.	
VI - -	July 29	1 empty wagon - -	- -	1.85	6204	- -	36.78	$\frac{1}{169}$	13.28	This wagon has only a platform surrounded by an open railing.
VIII -	July 30	1 tender - - - - -	- -	4.50	5967	- -	36.66	$\frac{1}{163}$	13.76	
III - -	July 29	1 loaded wagon - -	- -	4.65	7326	- -	37.16	$\frac{1}{197}$	11.36	This form gives a great hold to the air.
IV - -	July 29	1 loaded wagon - -	- -	5.15	6663	- -	36.95	$\frac{1}{180}$	12.42	
V - -	July 29	1 loaded wagon - -	- -	5.20	7455	- -	37.19	$\frac{1}{200}$	11.17	An axle-box very hot on arriving.
IX - -	July 31	1 tender - - - - -	- -	5.50	7266	- -	32.88	$\frac{1}{221}$	10.13	
II - -	July 29	5 loaded wagons - -	25.58	5.12	9324	10′.20″	38.19	$\frac{1}{244}$	9.17	
I - -	July 29	5 loaded wagons - -	31.31	6.26	9933	10.00	38.55	$\frac{1}{258}$	8.69	
XI - -	Aug. 1	10 loaded wagons and 1 tender (11 carriages)	48-72	4.43	10008	11.45	38.58	$\frac{1}{259}$	8.64	
X - -	July 31	14 loaded wagons - -	61.65	4.40	9579		35.32	$\frac{1}{271}$	8.26	
VII -	July 30	19 loaded wagons - -	92.00	4.84	10728	11.00	38.85	$\frac{1}{276}$	8.11	
XII -	Aug. 1	24 loaded wagons and 1 tender (25 carriages)	110.00	4.40	10668	- -	38.82	$\frac{1}{275}$	8.15	
XV -	Aug. 15	7 wagons 1 tender and 1 engine in front - -	40.59	4.00	8175	8.30	37.35	$\frac{1}{219}$	10.23	
XIII -	Aug. 2	17 wagons 1 tender and 1 engine - - - -	94.96	4.78	11262	- -	39.10	$\frac{1}{288}$	7.78	Including the friction of the engine.
XIV -	Aug. 2	20 wagons 1 tender and 1 engine - - - -	110.14	4.83	10911	12.10	38.75	$\frac{1}{282}$	7.96	

During all those experiments the weather was fair and calm. As we have said before, no particular precautions had been taken, nor had any thing been altered in the usual state of the wagons or rails. The circumstance of the trains passing over nine switches at the foot of the inclined plane, must make the results appear a little greater than they would generally be on any other part of the road taken at random.

Section 6.—*Friction of the intermediate Wagons of the Trains.*

We have already marked in the first six experiments the influence of the resistance of the air in the results. When five wagons move together, their resistance to the motion is 9.17 lbs. per ton; and if each of those five wagons move separately, their average resistance per ton is 11.65 lbs. The other experiments present similar results. By comparing large trains with those which are composed only of a small number of carriages, we constantly see the resistance diminish, when the mass which is drawn, although continuing to cut the air on the same surface, comprises, however, a more considerable weight.

The direct resistance of the air takes place only on the first carriage of the train. Now, the first six experiments made with a single wagon give us the resistance of a carriage when it advances the first. Deducting it, therefore, in the other experiments, we shall discover the resistance of the intermediate wagons of the trains; that is to say, the friction, independently of the direct resistance of the air.

The experiments III., IV., V., VIII., and IX. put together, give us the average friction of a loaded wagon at the head of the train equal to 11.77 lbs. per ton. Taking, therefore, experiment VII., for instance, the weight of the train was 25.58 t. Each ton had a resistance of 9.17 lbs.; thus the total resistance was 234.5 lbs. Deducting the re-

sistance of the first wagon at the rate of 5.12 t. × 11.77 lbs. = 60.25 lbs., there remain for the four following wagons 174.25 lbs., which, divided by the weight of those four wagons, make 8.50 lbs. friction per ton.

Section 7.—*Table of the Results of the foregoing Experiments on the Friction of the intermediate Wagons of the Trains.*

If we make the same calculations for each of the other experiments, and if we add to them the similar results, already presented for the three experiments where the engines had remained attached to the trains, the following table will be made out:—

RESISTANCE OF THE INTERMEDIATE WAGONS OF THE TRAINS, THAT IS TO SAY, AFTER DEDUCTION OF THE DIRECT RESISTANCE OF THE AIR ON THE FIRST CARRIAGE.

Number of the experiment.	Description of the trains.	Weight of the trains.	Average weight per carriage.	Resistance per ton of the first carriage of the train.	Resistance per ton of the intermediate wagons of the train.
		tons.	tons.	lbs.	lbs.
II .	5 wagons	25.58	5.12	11.77	8.50
I . .	5 wagons	31.31	6.26	11.77	7.92
XI .	11 carriages	48.72	4.43	11.77	8.33
X .	14 wagons	61.65	4.40	11.77	7.99
VII .	19 wagons	92.00	4.84	11.77	7.91
XII .	25 carriages	110.00	4.40	11.77	7.99
XV .	8 carriages	33.52	4.00	15.84	9.04
XIII .	18 carriages	86.76	4.78	13.78	7.21
XIV .	21 carriages	101.80	4.83	15.22	7.35
	126 carriages	591.00	4.78	,,	8.03

The average resistance is therefore no more than 8 lbs. per ton, if we take into account only the intermediate wagons of a train. Now, in all the cases we have to calculate, in respect to railways, the train is always preceded by

the engine. It is, therefore, upon that alone that the direct resistance of the air exerts its influence, and that resistance being already taken into account in what is called the friction or resistance of the engine, it is clear that all the wagons must be considered as intermediate carriages. Consequently, their proper resistance must only be reckoned at the rate of 8 lbs. per ton. It is upon this proportion that we shall establish the resistance of the trains in all our experiments.

In the foregoing tables, the average weight of a wagon was 4.78 t. That wagon placed at the head of the train, had a resistance of 11.77 lbs. per ton, or 56 lbs. for the whole; while, placed in an intermediate situation, its resistance was 8.03 lbs. per ton, or 38 lbs. in all. The difference between the results was owing to the obstacle of the air. The air created, therefore, a resistance of 17 lbs. to 18 lbs. on a wagon of a moderate height, as those were, and at the average speed of the experiments. That speed was of about 12 miles an hour, or 16 feet per second, a space of 10,000 feet having been, on an average, run over in 10 minutes.

This determination agrees with direct experiments made on the force of the wind. We know that when the wind has a velocity of 20 feet per second, it causes on a surface of a square foot a pressure of 0.915 lbs. or a little less than 1 lb. In other words a surface of one square foot cutting the air with a velocity of 20 feet per second meets with a resistance of 0.915 lbs. Thus a loaded wagon presenting a surface of about 22.5 square feet must meet, from the atmosphere, with a resistance of about 20 lbs.

The direct resistance of the air against the first carriage of the train, once deducted, the resistance per ton does no longer depend upon the number of wagons. The remaining differences seem to be the effect of accidental circumstances, such as the state of the rails, or the wind, or the greasing of the wheels, &c., which prevent those experiments from presenting a mathematical preciseness.

SECTION 8.—*Experiments on the Friction of Wagons without Springs.*

The foregoing experiments having been made with wagons mounted on springs and constructed on an improved principle, one might perhaps suppose that common wagons, having no springs, would offer a great resistance to the motion.

In order to clear up this point, some experiments were, at our request, undertaken on the Darlington Railway. They were conducted exactly on the same principle as the foregoing, by Mr. Robert B. Dockray.

The wagons employed were the common wagons in use on that line. Their wheels are 3 feet in diameter, like those of Liverpool. Their weight, when empty, is 1.30 t., and 4 t. including the load. They are not mounted on springs, and the axle is 3 inches in diameter at the bearing.

We have seen that in the Liverpool wagons the axle in the same part is only $1\frac{3}{4}$ inches in diameter. This difference arises from the circumstance that, in the Liverpool wagons, the support is *outside* the wheel, on a prolongation of the axle; and that part, the only service required of which is to support the wagon, may be reduced to so small a diameter without depriving the middle part of the axletree itself of its usual strength. In the Darlington wagons, on the contrary, the bearing is *within* the wheel, like in common carriages. The support takes place, therefore, not on a prolongation of the axle, but on the axle itself; and this part cannot be less than three inches in diameter, because it must not only bear the weight of the wagon but also maintain the wheels in a fixed situation, by resisting the lateral pressure and the twisting forces which are continually exerted against the wheels during the motion.

With those wagons the experiments on friction gave the following results:—

EXPERIMENTS ON THE FRICTION OF WAGONS WITHOUT SPRINGS.

Number of the experiment.	Number of wagons in the trains.	Distance run over by the wagons before they stopped.	Difference of level between the starting and arriving points.	Friction.	Friction per ton in lbs.
		ft.	ft.		lbs.
I - -	12	9,552	34.56	$\frac{1}{276}$	8.11
II - -	4	9,600	34.60	$\frac{1}{277}$	8.07
III - -	16	10,500	35.04	$\frac{1}{300}$	7.48
IV - -	8	9,894	34.82	$\frac{1}{284}$	7.88
				Mean	7.88

During those experiments, the wind blew with a moderate strength in favour of the motion, which is a point to be considered; for we know that trains of wagons are sometimes propelled to a considerable distance on railways, by the force of the wind alone. All the wagons were in good order, and particularly those of experiments III. and IV., which were, besides, the best on the line.

These experiments having, contrary to the natural expectation, given more advantageous results than those which had been obtained with wagons mounted on springs, it became necessary to determine exactly the influence of springs on the resistance to motion.

In consequence, the platform of a wagon mounted on springs, having been wedged so as to raise it *off* the springs, the wagon with pigs of lead, weighing 2 tons, and in that state it was left to its gravity on the inclined plane. The resulting friction was 8.58 lbs. per ton.

Then the wedges were struck out, so as to let the plat-

form descend on the springs again, and the experiments having been repeated, gave a friction, per ton, of 8.35 lbs.

There exists consequently, a small advantage in making use of springs; but that advantage is easily compensated by some adventitious circumstances, as better polished bearings, better greasing, a load giving less hold to the air, &c.; and, in one case as well as in the other, the *average* friction must be reckoned at 8 lbs. per ton.

CHAPTER IV.

OF THE FRICTION OR RESISTANCE OF THE ENGINES.

ARTICLE I.

OF THE FRICTION OF ENGINES WITHOUT LOAD.

Section 1.—*Of the different modes of Determination.*

After having determined the resistance opposed by the loads that are to be moved, it was also necessary to ascertain the resistance belonging to the moters themselves, for it is only the surplus of their force, beyond the power they require to move themselves, which those moters can apply to the traction of loads.

The friction of a locomotive engine is the resistance which that engine opposes to motion. It is the force that must be applied to it, to overcome all the frictions that oppose its progress, at the moment it executes the traction of a train. At that moment it must evidently possess: 1st, a certain power sufficient to make the train advance or to overcome the resistance of all the loaded carriages; 2d, another power sufficient to propel the engine itself along and overcome its own friction. It is this second power, the power that propels the engine, which is the friction of that engine,

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or, rather, which is equal to the *friction of that engine;* whilst the first is the *resistance of the load,* and whilst both the powers together constitute *the total power applied by the moter.*

The power required to move a locomotive engine differs according to three different circumstances.

1st. If the steam remains shut up in the boiler without having any access to, or exercising any pressure on, the mechanism, so that the progress of the engine be produced by an external agent, the engine, moreover, drawing no load.

2d. If the steam is the agent that produces the motion; but if, as in the first case, there is no train attached to the engine.

3d. If the engine cannot move without drawing after it a load, the resistance of which, creating an increase of pressure on all the parts of the mechanism, must necessarily augment the friction on every one of its joints, and, consequently, the total resistance of the engine.

The difference between the first and second case cannot be very great; for, in both circumstances, the load of the engine remains the same, being nothing more than its own weight. Besides, by whatever means it is made to move, it advances; so that, at every turn of the wheel, there is a complete revolution, and consequently, a complete friction of the whole mechanism. The steam would have applied a certain force to make the engine move. That force would have produced pressures, and, consequently, proportional frictions on all the compressed points, as upon the crank of the axletree and all the joints in general. Now, as soon as we make the engine advance, we apply a force equal to that which the steam would have applied. Consequently, we produce on the crank and on all the joints the same friction that would have been produced by the force owing to the steam. Of all these joints, those only upon which the steam acts in a direct and particular manner, ceased to be compressed equally in the two cases. These parts being

strongly pressed against one another, when the steam is admitted into the cylinder, cease to experience that pressure, and have, in consequence, evidently less friction when the steam takes no part in the creation of the motion. But the only part on which the steam exercises a direct pressure are the two slides.

The surface of the slide, on which the pressure of the steam takes place, is, in general, $7\frac{1}{2}$ inches long to 6 inches broad, or 45 square inches, which makes 90 square inches for the two slides together. When we talk of the engine moving alone, and without drawing any load after it, we cannot suppose that the pressure of the steam in the boiler need to surpass 10 lbs. We shall find, by experiment, that it may happen not to be above 4 or 5 lbs. The pressure exercised by the steam on the slides amounts, therefore, at most, to 900 lbs. So that, taking the friction of iron on iron, ground and polished, at $\frac{1}{10}$ of the pressure,* we shall have a friction of 90 lbs. But we know that the real resistances on different points of an engine are in the ratio of the velocity with which those parts move. The slide only moves three inches for each stroke of the piston, or half a foot for each turn of the wheels; that is to say, that it only runs over a space of half a foot, while the engine having a wheel of five feet, advances 15.71 ft. The friction of the slide, considered as opposing itself to the motion of the engine, creates, therefore, a final resistance of only $\frac{90}{2 \times 15.71}$ lbs. or about 3 lbs. From which we see, that, in practice, the friction occasioned either in the first case or in the second, may be considered as being the true friction of the engine, when it draws no load.

As for the difference between these first two cases and the third, we know that the friction is always in a direct ratio to the pressure. Now, it is evident that the pressures which take place on the rubbing parts of the engine, vary in pro-

* According to the experiments of Coulumb on the resistance of surfaces.

portion to the load it draws. That principle is true, provided the weight of the engine itself is taken as a part of the load. The only parts which are excepted from that rule are: the piston, which remains in all cases pressed in the same manner, the steam having no access into its interior; the slide, the friction of which varies with the pressure in the boiler, which depends indirectly upon the load; and, lastly, the eccentrics, the friction of which follows the friction of the slides. All the other parts of the engine are subject to the rule laid down above. The principal pressure takes place on the crank of the axle, and that pressure is exactly in proportion to the load.

There must consequently be a considerable difference in the friction of an engine when loaded or when without a load. We shall have recourse to experiments to determine that difference.

First, we shall endeavour to make ourselves acquainted with the friction of the engine without a load, and then we shall come back to the second part of the problem, which consists in determining the influence of the load upon that friction. By that means we shall be able to calculate the resistances of locomotive engines in all circumstances.

Section 2.—*Friction of the Engines determined by the least Pressure.*

The considerations above stated, which tend to prove that the power necessary to move an engine is very nearly the same, whether the force of the steam itself, or any other external agent, is employed, furnished us with two means of ascertaining the friction of engines without a load. The first consisted in seeking what was the least pressure of steam required by a locomotive engine to put itself in motion on the rails, when it had no other resistance than its own to overcome; the second was the method already employed in regard to the wagons. Both were successively tried.

The principle upon which the first of these two methods is founded is the following:

If we find that the steam, by causing a known effective pressure per square inch, can make the engine advance, the area of the two pistons in square inches being known, it is easy to calculate the total force applied by the steam on those two pistons. That force being sufficient to make the engine advance,—that is to say, to conquer its resistance,—it gives of course the value of that resistance. It must only be observed, according to the principle known in mechanics by the name of *the principle of virtual velocities*, that the pressure exercised on a part of an engine, being transmitted to another part of the same engine, retains the same intensity only in case the two parts have the same velocity. If not, the force or pressure is reduced in an inverse ratio to the velocity of the points of application. This principle appears in an evident manner and *a priori*, in simple machines like the lever, the roll, the pulley, &c. Inspection alone is sufficient to demonstrate that if a force can, by the aid of the machine, raise a weight four times as great as itself, it is only by travelling, in the same space of time, four times as far as the weight it raises. In the case before us, the velocity of the piston is to that of the engine as twice the stroke is to the circumference of the wheel, the piston giving two strokes while the wheel turns once round. A force applied on the piston produces, therefore, in regard to the progress of the engine, an effect reduced in the same proportion, that is to say, as twice the stroke is to the circumference of the wheel.

Let d be the diameter of the piston, and π the ratio of the circumference to the diameter, $\frac{1}{4}\pi d^2$ will be the area of one of the two pistons; and p being the *effective* pressure of of the steam per square inch,

$$\frac{1}{2}\pi d^2 p$$

will be the *effective* pressure upon the two pistons. If, moreover, l express the length of the stroke, and D the

diameter of the wheel, the effective force of transfer resulting for the engine, in consequence of that pressure, will be

$$\tfrac{1}{4}\,\pi\, d^2\, p \times \frac{2l}{\pi D}, \text{ or } \frac{pld^2}{D},$$

which, according to what we have said, gives the measure of the resistance of the engine.

Here it must be noticed that we suppose the pressure of the steam in the cylinder to be equal to that in the boiler. The reason is, that in the experiments we shall have occasion to make, the motion of the engines being always extremely slow and the regulator completely open, the two pressures have time to put themselves in equilibrium, and are consequently equal. It must also be observed, that the *effective* pressure p of the steam, or the surplus of the total pressure over that of the atmosphere, is not the true moving power residing in the steam. That moving power is the *total* pressure of the steam, which we shall express by P. But, on the other hand, the true resistance on the piston is neither that only which results from the traction of the engine. It comprises also the atmospheric pressure, which takes place either directly or intermediately on the other face of the piston, as well as upon every other body in communication with the atmosphere. So, we omit on both sides an equal quantity, viz. the atmospheric pressure. Nothing prevents us here from simplifying in that manner; because, having to compare the power and the resistance only in a case of equality, that equality is not destroyed by subtracting an equal number on each side.

To succeed in ascertaining the least pressure by which the engine could be moved, it was necessary to take the engine at the instant when it furnished the steam at a very low degree of elasticity. In the evening, after the work was finished and the fire taken out of the fire-box, the water of the boiler began to lose its heat, and the steam that it generated also gradually lost its force. This was the proper

moment to ascertain the least pressure by means of which the engines were able to advance on the rails. The spring-balance that shut the safety-valve enabled us to ascertain the pressure of the steam in the boiler, by loosening the spring until it stood in exact equilibrium with the pressure. It was then easy to calculate the pressure from the degree marked on the balance. However, to make all calculation unnecessary, the engine was brought to the mercurial gauge, which gave immediately the pressure per square inch in the boiler, at the moment of the experiment. It is in that manner that the following experiments were made:—

I. On the 5th of July, the ATLAS engine, cylinders 12 inches diameter, stroke 16 inches, weight 11.40 t., wheels five feet, four wheels coupled, was submitted to the experiment separated from its tender.

The spring of the balance having been successively loosened, to show the pressure of the steam in the boiler in proportion as it went down, the following trials were made:—

At 2 lbs. pressure, marked by the balance, the engine moved backwards and forwards, passing from a state of rest to one of motion, or conquering, besides the friction, what is called the *vis inertiæ* of the mass of the engine; that is to say, not only maintaining an acquired velocity, but acquiring one, which proves a surplus of force in the moving power.

At 1 lb. pressure, marked in the same way, the engine started, passing from a state of rest to one of motion.

The pressure diminishing a little more, the engine *continued* moving. At that moment we brought it under the mercurial gauge. It marked 4 lbs. effective pressure per square inch in the boiler, the valve then bearing no more than the weight of the lever, or a little less, which could not be ascertained, the balance not going below zero.

The cylinder being 12 inches in diameter, the area of the two pistons was 226 square inches. Thus a pressure of 4 lbs. per inch produced on the pistons a force of 226 × 4 = 904 lbs., that is to say, was able to move a resistance of

904 lbs. at the velocity of the piston. But at the velocity of the engine, which is greater in the proportion of the circumference of the wheel to twice the stroke, or $\frac{15.71}{2 \times 1.33}=$ 5.887, that same force was only able to overcome a resistance of $\frac{904}{5.887}=154$ lbs.

Thus, as we have seen that the engine continued moving at the moment it was brought under the steam gauge, though the pressure was then reduced to 4 lbs., we see that the resistance of the engine did not exceed 154 lbs.

This first experiment was made with the engine separate from its tender, with a view not to counteract one resistance by the other; but, in wishing to apply it to lighter engines, of which the wheels were not coupled, a difficulty occurred. The pressure required for the engine to move without tender was so very low, that the spring-balance could not mark it, that pressure being less than the weight of the lever itself. Another inconvenience of that low pressure was, that it could only be obtained at the moment the boiler regenerated no more steam at all; the consequence of which was that at that moment the pressure diminished so rapidly that no confidence could be put in the accuracy of the experiment.

But as the resistance of the tender could be easily calculated by the experiments made on the friction of the carriages, and already inserted above, it was also easy to take it into account. Thus, by having the tender attached to the engine, the experiment presented the same degree of accurateness, with more facility in observing the pressure of the steam. It is for that reason that, in the following experiments, the tender was no longer separated from the engine:—

II. On July 21, the Sun engine, cylinders 11 inches, stroke 16 inches, weight 7.91 tons, wheels 5 feet; only one pair of wheels worked by the piston, was submitted to the same experiment.

At 6 lbs. pressure by the balance, the engine started, followed by its tender full of coke and water.

At 4 lbs. the same.

At 2 lbs. the same.

At 1 lb. pressure the engine started also.

With the weight of the lever alone, the balance marking no pressure at all, the engine started again.

The pressure still a little farther diminished, the engine did not start, but, once put in motion, continued going.

At that instant we brought it under the mercurial gauge; it marked $5\frac{1}{2}$ lbs. pressure per square inch, so that at that pressure the engine can move, followed by its tender.

The area of the two pistons (11 inches in diameter) being 190 square inches, a pressure of 5.5 lbs. per inch, produced on the piston a force of 190×5.5 lbs. $=$ 1,045 lbs. at the velocity of the piston, and thus a draft of $\frac{1,045}{5.887} = 177.5$ lbs. at the velocity of the engine. That was then the force required to move the engine and its tender. Now the tender, filled with water and coke, weighed 6.50 tons, and according to the experiments made on the friction of the carriages, each ton required to put it in motion a power of 8 lbs. The tender consumed, therefore, for its share, a force of 6.50 lbs. $\times$ 8 $=$ 52 lbs. Thus the resistance proper to the engine was 177 lbs. — 52 lbs. $=$ 125 lbs.

III. On July 23, the same engine, the Sun, was tried again at the least pressure, and gave the following results:—

At 4 lbs. marked on the balance, the engine started, followed by its tender filled with water and coke.

At 1 lb. marked on the balance, it started rapidly.

At 0 of the balance, it still started with facility.

At 2 lbs. under zero, it still moved at the rate of two or three miles an hour.

At that instant it was put under the mercurial gauge, which marked $4\frac{3}{4}$ lbs. We may consider that, in this experiment, we had arrived at the lowest pressure by which the

engine could move. According to the calculation established above, that pressure of 4¾ lbs. gave a force of 902.5 lbs., which, referred to the motion of the engine, produced a traction of 153 lbs. Deducting 52 lbs. for the resistance of the tender, there remained 101 lbs. for the resistance of the engine.

IV. The same day, the Firefly engine, cylinders 11 inches, stroke 18 inches, weight 8.74 tons, wheels five feet, one pair of wheels only worked by the piston, was submitted to the same trial.

At 3 lbs. marked on the balance, it started, followed by its tender filled with water and coke.

At 2 lbs. also.

At 0 it started also, came back, and went off again in a contrary direction.

At 1 lb. under 0, it still started forwards and backwards. The pressure diminishing a little more, the engine has just power enough to move.

At that moment it was brought to the mercurial gauge; the pressure was found to be 4½ lbs. According to the proportions of the engine mentioned above, a pressure of 4½ lbs. per square inch on the piston produced a traction on the engine of 163 lbs.; deducting 52 lbs. for the tender, there remained for the proper resistance of the engine 111 lbs.

Section 3.—*Friction of the Engines determined by the Dynamometer.*

While the resistance of the engines was being determined in that manner, other trials were also made, to obtain a valuation of that same resistance by means of the dynamometer.

V. On July 22, in the morning, the Vulcan engine, cylinders 11 in., stroke 16 in., wheels 5 ft., weight 8.34 t., one pair of wheels only worked by the piston, being ready to set off for Manchester, its boiler full of water, and its

fire-box of coke, was separated from its tender. A circular spring-balance was fixed to the engine, and a lever was passed through the ring of the balance, so that two men might draw the engine by means of the lever.

The engine was first put in motion by five or six men. The first impulse being given, the two men that pushed on the lever maintained it without difficulty in motion, at the rate of two or three miles an hour. The index of the balance oscillated very much. It varied generally from 130 to 170 lbs., giving an average traction of 150 lbs.

The balance was afterwards taken off from the front of the machine, and fixed behind on the Liverpool side, when the same experiment repeated, gave an average traction of 140 lbs. The index still oscillated about 20 lbs. above and below that point.

Average of the two experiments, 145 lbs.

The engine was ready to go off, and it had already made some turns on the rails, in order to light its fire and fill its boiler, so that the grease that anointed the rubbing parts was melted, and the oil perfectly liquid. But the experiment taking place in the interior of the Liverpool station, in a great thoroughfare, the rails were covered with cinders and dirt; a circumstance which considerably augmented the resistance to the motion.

VI. On July 23, in the evening, the Sun engine, of which the proportions have already been given above, and the weight of which is 7.90 t., was tried in the same manner. It gave 100 lbs. traction towards Manchester, and 130 lbs. backwards, towards Liverpool. Average 115 lbs. The boiler of the engine was full of water; the fire-box empty.

VII. On the same day, the Firefly, already described, the weight of which is 8.74 t., drawn by the dynamometer, required 125 lbs. in one direction, and 130 lbs. in the other. Average traction 127½ lbs. The boiler of the engine was full of water; the fire-box empty.

VIII. On the same day, the Fury engine, cylinders 11

in., stroke 16 in., wheels 5 ft., of which only 1 pair are worked by the piston, weight 8.20 t., required in advancing towards Manchester 100 lbs. traction, and 110 lbs. going back towards Liverpool. Average 105 lbs.

These experiments took place on the engines separated from their tenders. They were made on a part which is considered as being exactly level. We may, however, suppose, that on the precise spot where the engine was, the soil was not perfectly horizontal, and that that was the cause of the slight difference in the resistance, observed between one direction and the other.

SECTION 4.—*Friction of the Engines calculated by the Angle of Friction.*

These results did not differ considerably from the preceding ones; but as in all the experiments, the index of the balance varied extremely, in consequence either of the slight inequalities of the road, or of the jerks given by the men that drew the engine, the average traction was very difficult to ascertain exactly. Besides, the dirtiness of the rails augmented considerably the resistance. It was, consequently, desirable to get those results verified by a different method, admitting of a greater accuracy.

For that reason the same engines were submitted to experiments similar to those which had served to calculate the friction of the wagons.

IX. On July 30, the JUPITER engine, cylinders 11 in., stroke 16 in., wheels 5 ft., only one pair of wheels worked by the piston, weight 7.90 t., was brought on the inclined plane of Sutton, to the same place where the experiments on the friction of the wagons had been made. It was separated from its tender, and left to its gravity on the plane.

Gone off from the post No. 0, it continued its motion until 249 ft. beyond the post No. 18, and ran during 7′ 12″. This experiment gives: Distance travelled 6189 ft ; differ-

ence in level between the points of departure and arrival, 36.78 ft.; consequently, friction $\frac{1}{168}$ of the weight, or $\frac{7.90t.}{168.} = \frac{17{,}696\,lbs.}{168} = 105$ lbs. This result includes the direct resistance of the air at a velocity of 9 to 10 miles an hour.

X. On July 31, the ATLAS engine, cylinders 12 in., stroke 16 in., wheels 5 ft., four wheels coupled, weight 11.40 t., was brought to the same place. Not having been in time, the train could not be stopped precisely at the suitable point, and the engine was already 99 ft. beyond the post No. 1. It was not possible to push back the considerable train it was drawing; so that the starting-point having been carefully determined, the engine was left to itself at that point, and ran to 273 ft. beyond the post No. 17.

The distance travelled by the engine was 5454 ft., and the difference in level between the points of departure and arrival, 32.07 ft. Thus the friction was $\frac{1}{170}$ of the weight, or 150 lbs. This calculation includes the direct resistance of the air, at an average velocity of 8 to 9 miles an hour.

XI. On August 1, the same engine, the ATLAS, brought to Sutton inclined plane, and the centre of the engine being carefully placed facing the usual starting post, was left to its gravity on the plane. It ran until 45 ft. beyond the post No. 14.

Distance travelled in 5′ 40″, 4665 ft., total descent 35.40 ft.; friction $\frac{1}{132}$ of the weight, or 194 lbs.

The engine had been repaired the night before. The connecting-rods being too weak had been changed, and the new ones were not yet exactly adjusted to their proper length. The resistance they produced, acting upon the wheel at the end of a lever of one foot, which is the radius of the crank-arm by which they turn the wheel, produced the effect of a powerful brake to check the velocity of the engine. This friction of the ATLAS is, consequently, not

applicable to the experiments made with that engine before August 1.

XII. On August 1, the Vesta engine, cylinders $11\frac{1}{8}$ in., (this engine had originally cylinders of 11 in. diameter, but in repairing it, the cylinders were newly bored, which augmented their diameter by one-eighth of an inch,) stroke 16 in., wheels 5 ft., two wheels only worked by the pistons, weight 8.71 t., was submitted to the same trial. Setting off from post No. 0, it continued in motion to 33 ft. beyond post No. 11. It ran thus in 6′, over a space of 3663 ft., with a difference in level between the departure and the arrival of 33.07 ft.; which establishes the friction at $\frac{1}{104}$ of the weight, or 187 lbs.

This engine had been repaired, since which it had only made two or three trips at the time of the experiment. The different pieces were not yet well fitted, nor the joints very easy. Thence arose the increase of resistance observed in it, comparatively with the other engines.

XIII. On August 2, the Fury engine, cylinders 11 in., stroke 16 in., wheels 5 ft., not coupled, weight 8.20 t., left the usual starting-point, and stopped at 48 ft. beyond the post No. 18, running in 7′ over a space of 5,988 ft., with a difference of level between the points of departure and arrival of 36.68 ft.; which put the friction at $\frac{1}{163}$ of the weight, or 113 lbs.

XIV. On August 2, the Vulcan engine, cylinders 11 in., stroke 16 in., wheels 5 ft., not coupled, weight 8.34 t., left to its gravity from a point situated at 27 ft. above the usual starting-point, ran in 6′ 30″ over a space of 5,391 ft., with a difference of level of 36.52 feet., which puts the friction at $\frac{1}{148}$ of the weight, or 127 lbs.

XV. On August 4, the Leeds engine, having the same proportions as the Fury and the Vulcan, weight 7.07 t., ran in 6′ 30″ over a space of 5,472 ft., on a slope of 36.32 ft. Thus the friction of the engine was $\frac{1}{150}$ of its weight, or

105 lbs. (one of the pistons of the engine creaked for want of greasing.)

XVI. On August 15, the same engine, the Leeds, went off from the same point, and ran over 5,061 ft. in 6′, on a slope of 35.86 ft., which puts the friction of this engine at $\frac{1}{141}$ or 112 lbs. (one of the pistons creaked, as in the foregoing experiment.)

All these results include the direct resistance of the air against the engine, at an average velocity of 10 or 12 miles an hour.

Section 5.—*Table of the results of the foregoing Experiments on the Friction of Engines.*

Placing all those experiments next to each other, we form the following table:—

EXPERIMENTS ON THE FRICTION OF LOCOMOTIVE ENGINES.

Number of the experiment.	Date of the experiment.	Name of the engine.	Diameter of the cylinder.	Stroke of the piston.	Diameter of the wheel.	Weight of the engine.	Mode of determination.	Friction resulting from the experiment.	Friction of the engine.	Observations.
	1834.		inches.	inches.	feet.	tons.		lbs.	lbs.	
I - -	July 5	ATLAS	12	16	5	11.40	by the least pressure	154	152	The engine has 6 wheels, 4 of which are worked by the piston.
X - -	July 31	—	12	16	5	11.40	by the angle of friction	150		
XI - -	Aug. 1	—	12	16	5	11.40	by the angle of friction	194	194	The connecting-rods working hot.
II - -	July 21	SUN	11	16	5	7.91	by the least pressure	125		
III - -	July 23	—	11	16	5	7.91	by the least pressure	101	114	
VI - -	July 23	—	11	16	5	7.91	by the dynamometer	115		
IV - -	July 23	FIREFLY	11	18	5	8.74	by the least pressure	111	119	
VII -	July 23	—	11	18	5	8.74	by the dynamometer	127		
V - -	July 22	VULCAN	11	16	5	8.34	by the dynamometer	145	136	
XIV -	Aug. 2	—	11	16	5	8.34	by the angle of friction	127		
VIII -	July 23	FURY	11	16	5	8.20	by the dynamometer	105	109	
XIII -	Aug. 2	—	11	16	5	8.20	by the angle of friction	113		
XV -	Aug. 4	LEEDS	11	16	5	7.07	by the angle of friction	105	108	
XVI -	Aug. 15	—	11	16	5	7.07	by the angle of friction	112		
IX - -	July 30	JUPITER	11	16	5	7.90	by the angle of friction	105	105	
XII -	Aug. 1	VESTA	$11\frac{1}{8}$	16	5	8.71	by the angle of friction	187	187	The engine rather stiff, having just come from repairing.

Considering these results, we see that, setting aside the VESTA, which was particularly circumstanced, the locomotive engines, with uncoupled wheels, had an average resistance of only 115 lbs.; and the ATLAS, with coupled wheels, and of a considerable weight, only 152 lbs., when not thwarted by his connecting rods.

However, to provide a datum for all cases, it may be concluded from the total weight of the engines, compared with their friction, that locomotive engines, well constructed and in good order, have a resistance of 15 lbs. per ton of their weight. This is the result which may be reckoned upon, when an engine is not yet constructed, and when, consequently, one can estimate only by guess what will be its future friction.

We have already observed, that the experiments with the dynamometer and by the least pressure, were made on a spot where the rails offered more resistance than along the line. On the other hand, the experiments on the angle of friction took place at a point of the railway where there were nine crossings to get over. These obstacles acted more particularly on the engines, because they occurred in a place where the velocity of the motion was already considerably diminished. We may, therefore, when we have engines well constructed, kept in good repair, and on the Liverpool model, calculate on the result we have obtained, without fear of putting the resistance too low.

In each of the experiments with the engines, which we shall have occasion to relate, we shall take not the average result, but the individual friction of each of them, as it has been determined.

ARTICLE II.

OF THE ADDITIONAL FRICTION OF LOCOMOTIVE ENGINES, IN PROPORTION TO THE LOAD THEY DRAW.

SECTION 1.—*Of the Mode of Calculation.*

We have now determined the friction or resistance of locomotive engines, when they draw no load. We have, however, already shown, that the friction must increase in proportion to the load the engine draws. The aim of our researches must, therefore, now be, to discover the amount of friction for different loads, in order to deduce from it the surplus of resistance created in the engine by each ton of the load.

When an engine executes the traction of a train, we know the pressure in the boiler by inspecting the spring-balance; but we do not know the pressure of the steam in the cylinder, because, in passing from the boiler to the cylinder, the elastic force of the steam changes, as will be seen hereafter. If we could know, *a priori*, the pressure in the cylinder; if, for instance, it were possible to apply a mercurial gauge to it, we might immediately deduce the friction of the engine corresponding to that load.

In fact, if by hypothesis we know the pressure in the cylinder, or on the piston, by calculating the total effect of that pressure on the area of the piston, we find the exact valuation of the power applied by the engine.

On the other hand, we also know the resistance opposed to the motion; it being composed of the resistance of the train and of the engine.

Besides, if the engine, in drawing that load, increased constantly in velocity, it is clear that there would be an excess of power over the resistance. If, on the contrary, the velocity were to diminish gradually, the power would be in-

ferior to the resistance; but if we take the engine at the moment it has acquired a certain uniform velocity, and if that velocity be maintained without alteration, the power the engine thus applies must necessarily be exactly equal to the resistance it undergoes, or else there would be either acceleration or retardation in the motion.

Thus we know the power applied by the engine; we know the resistance to the motion, which is the sum of the resistance of the train and that of the engine; and, besides, this sum is equal to the power applied: consequently, the resistance of the engine is equal to the power applied, less the resistance of the train.

This mode would give thus immediately the friction of the engine, if we knew the pressure in the cylinder.

But there are cases in which the pressure in the cylinder is really known *a priori*, and is equal to the pressure in the boiler. These cases are those in which the engine attains the limit of its power with the pressure at which it is working; that is to say, when it draws the greatest load it can draw with that pressure.

In fact, as by the hypothesis the engine has arrived at the limit of its power, the pressure in the cylinder cannot be less than in the boiler; for, if it were, by diminishing the velocity, which is the only obstacle to the establishment of an equilibrium of pressure between the two vessels, one might give to the steam time to rise in the cylinder until it would equal the pressure in the boiler, and then the effect would be augmented. That is to say, that the engine might draw a greater load, provided its velocity were diminished. On the contrary, as soon as the pressure in the cylinder becomes equal to that in the boiler, there is no farther diminution of velocity that will permit to increase the load; for an increase of load requires an increase of moving power, which is no longer possible.

Thus, in case one has attained the *maximum* load of the engine, the power applied is known *a priori;* and one may,

as we have actually done above, deduce from it the corresponding friction of the engine.

Let us then suppose, that in an experiment we have attained the limit of the power of the engine. Let d be the diameter of the piston, and π the ratio of the circumference to the diameter, $\frac{1}{4}\pi d^2$ will be the area of the piston, and $\frac{1}{2}\pi d^2$ the area of the two pistons together. Let also p be the effective pressure per unit of surface of the steam in the boiler, such as it has been observed during the experiment; it is clear from what we have said above, that $\frac{1}{2}\pi d^2 p$ is the force then applied to the piston.

Calling D the diameter of the wheel, and l the length of the stroke, the force applied to the piston is, when transferred to the engine, reduced in proportion to their respective velocities, or in the proportion of $\frac{2l}{\pi D}$. Thus, after its transfer to the engine it is expressed by

$$\frac{1}{2}\pi d^2 p \times \frac{2l}{\pi D} = \frac{pd^2 l}{D},$$

which is the expression of the power of traction as applied to the progress of the engine.

On the other hand, M being the weight of the load, expressed in tons, and n representing the resistance for each ton of the load, such as we have determined it in the preceding chapter, nM is the resistance of the train. Finally, if we represent by X the proper resistance or friction of the engine,

$$nM + X$$

will be the total resistance offered to the motion of the engine.

Having seen that, when the motion is uniform, the power applied by the engine is equal to the resistance, we have

$$\frac{pd^2 l}{D} = nM + X;$$

and finally,

$$X = \frac{pd^2l}{D} nM,$$

which equation gives us the value we sought of the friction of the engine.

In this equation p is the effective pressure in lbs. per square inch in the boiler; d the diameter of the piston expressed in inches; l the length of the stroke; and D the diameter of the wheel, both expressed either in inches or in feet, which is indifferent, equation containing only their ratio. The number n, which is the resistance per ton, is 8 lbs.; and thus the value of X, when found, will also be expressed in lbs.

Here, as well as in the experiments made above with engines without load, we do not, in calculating the resistance, take into account the atmospheric pressure; because, also, in calculating the power, instead of reckoning the *total* pressure of the steam, we can only reckon its surplus above the pressure of the atmosphere. In doing this, we only suppress on each side two equal forces which equilibrate. Having here, as before, only to compare the power and the resistance in the case of equality, the substraction of an equal quantity can take place on both sides without altering the result.

The formula we have obtained is very simple, and the principle it represents will easily give us the resistance of the engine, in all the cases in which it has attained the limit of its power. All that remains to be done, is therefore to arrive at that point.

In consequence, experiments were made in that view, sometimes taking the greatest loads the engine was able to draw, and at others only middling loads, but lowering the pressure, by means of the spring-balance, as much as possible, without stopping the train.

Those experiments were made on three inclined planes of the Liverpool and Manchester Railway; viz. Sutton plane

inclined at $\frac{1}{89}$; Whiston plane inclined at $\frac{1}{96}$; and the rise of Chatmoss at $\frac{1}{1300}$.* In estimating the resistance on these planes it is clear that the gravity of the mass, decomposed along the plane, forms an additional resistance to the friction of the carriages; so that the resistance of the train, not including the friction of the engine, is then composed of the friction of the wagons, at the rate of 8 lbs. per ton, and moreover of the gravity of the total mass in motion on the plane. Thus a train of 40 t., drawn by an engine weighing 10 t., offers on Sutton inclined plane the following resistance:—

	lbs.
49 × 8 lbs. = 320 lbs. friction of the carriages at 8 lbs. per ton - - - - - - - -	320
$\frac{40 \times 2240 \text{ lbs.}}{89} = 1{,}006$ lbs. gravity of the 40 t. (reduced in lbs.) on a plane inclined in the ratio of $\frac{1}{89}$ -	1,006
$\frac{10 \times 2240 \text{ lbs.}}{89} = 251.6$ lbs. gravity of the engine on the same plane - - - - - - - -	252
Total resistance, not including the friction of the engine	1,578

And as we know that on a dead level a ton only requires 8 lbs. traction, we see that the train going up the plane is equal in that circumstance to a load on a dead level, of $\frac{1578}{8} = 197\frac{1}{4}$ t.

This is the manner in which the calculation will be made in the following experiments.

We give a considerable number of experiments, because having to apply to the wagons their average resistance per ton, the greater the number of carriages, the more accurate will be the calculation.

* See the Section of the Liverpool Railway, Chap. V., Art. VII., § 1.

SECTION 2.—*Experiments on the additional Friction of Engines.*

I. On July 22, 1834, the VULCAN engine, cylinders 11 in., stroke 16 in., wheels 5 ft., weight 8.34 t., ascended *Sutton* inclined plane with a first-class train of nine carriages, among which the mail and two empty trucks; weight of the train, tender included, 39.07 t.

The velocity of 26.6 miles, before arriving at the plane, settled at the rate of 20 miles an hour for the first half of the ascent, took then an average of 11.42 miles, and went down to 7.5 miles in the last quarter of a mile of the ascent, which is a little steeper than the rest.

The spring-balance of the engine, fixed at 31, as a point of departure, marked 36, which by the mercurial gauge corresponds to 57.5 lbs. effective pressure per square inch.

In consequence of the proportions of that engine, we have:

190 area of the two cylinders in square inches, multiplied by
57.5 lbs. pressure of the steam per square inch in the boiler or on the piston, makes
10,925 lbs. force applied on the piston; which being transferred as a power of traction to the engine, the velocity of which is 5.887 times greater, gives

$\frac{10,925}{5.887}$ lbs. = 1856 lbs. power applied to make the engine advance.

On the other hand, the resistance was

39.07 × 8 lbs. =....813 lbs. resistance, owing to the friction of the carriages.

$\frac{47.41 \times 2240 \text{lbs.}}{89}$ = 1193 resistance owing to the gravity of the total mass, train and engine.

1506 total resistance.

Thus:

1,856 lbs. power applied.
—1,506 resistance, equal to $188\frac{1}{4}$ t. on a level.

350 corresponding friction of the engine.

As we have said, the average velocity of the ascent was 11.42 miles per hour, and the velocity at the top of the plane 7.5 miles per hour.

In all the experiments we give those two velocities separately, because the engine having a great impulse on arriving at the plane we wish as much as possible to disengage that acquired velocity from the velocity proper to the motion. If we were to take 11.42 miles as the velocity of the motion, it would be a little too much, being complicated with the first impulse. On the other hand, by taking 7.5 miles we should commit a contrary error, because the last quarter of a mile of the ascent is steeper than the rest, and surpasses the inclination of $\frac{1}{89}$, on which our calculation is founded.

They call first class trains those which carry travellers, and go from Liverpool to Manchester without stopping. The carriages of those trains are never weighed. In all the experiments we have calculated them at an average weight of 4.73 t. loaded, and the mail coach at 3.44 t. The tender is reckoned at the rate of 5 t., or 5.50 t. according to the quantity of water and coke it contains at the moment of the experiment. The weight of the wagons, whether empty or loaded, is taken *exactly* in tons, cwts., quarters, and pounds. To simplify we shall express it here in tons and decimal fractions of tons.

II. On July 22, 1834, the same engine, the Vulcan, ascended *Whiston* inclined plane with a first-class train of 9 carriages, amongst which were the mail and two loaded trucks; weight of the train, tender included, 41.32 t. The velocity remained uniform during the ascent at 18.75 miles an hour, diminishing only to 12 miles an hour on the last quarter of a mile. The balance fixed at 31 marked 36, or

effective pressure by the mercurial gauge 57.5 lbs. per square inch in the boiler.

This experiment gives:

lbs.	
1,856	power.
1,489	resistance, equal to 186 t. on a level.
367	corresponding friction of the engine.

III. On July 23, 1834, the Atlas, cylinders 12 in., stroke 16 in., wheels 5 ft., weight 11.40 t., balance fixed at 50. lbs. as a point of departure, started from Liverpool with a train of 40 wagons weighing exactly 190 t., and, including the tender, 195.50 t.

The help of two other engines was necessary for the moment of starting. On *Whiston* inclined plane the train was helped by four engines; viz. two in front of the train, the Ajax and the Experiment, and two behind, the Sun and the Goliath. Drawn thus by five locomotive engines, the train went up the plane without a moment's delay; and once at the top, the Atlas resumed alone the haulage.

Arrived at the rise of *Chatmoss*, the engine with its whole train, ascended it without help for a space of 5½ miles. Its velocity was, however considerably reduced. The first six quarters of a mile were travelled with a uniform velocity of 15 miles an hour, pressure 51 by the balance, or 54 lbs. by the mercurial-gauge. During the four following quarters the velocity was 10 miles an hour, same pressure. Here began a steeper ascent for half a mile. At this point the velocity decreased rapidly. During the first quarter of a mile it fell from 10 miles to 6 miles an hour; during the second it fell to 3½ miles, and continued diminishing to the end of the pass. In proportion as the velocity diminished the pressure rose; first to 51½, then to 52 by the balance, where it stopped, pressure corresponding with 55 lbs. by the mercurial-gauge. After the passage of the obstacle the velocity increased again to 4½ miles, then

to 7½ miles an hour; after which it settled again for the rest of the ascent at its regular rate of 15 miles an hour. At the same time the pressure went down again to 51 by the balance, or 54 lbs. by the mercurial-gauge.

At passing a second similar irregularity of short duration, near the bridge on the Bridgewater Canal, the same effects were produced. The velocity was again reduced to 3½ miles, and the pressure rose again to 52 by the balance.

The irregularity which exists on Chatmoss is an inclined plane rising at the rate of 8 feet per mile, or $\frac{1}{660}$, and the other parts of the moss have a much smaller inclination, so that the average inclination is no more than $\frac{1}{1300}$; but the difficult pass is only half a mile long. When a mass of 200 t. arrives with the velocity of 15 miles an hour, and has consequently a considerable momentum, an obstacle, the inclination of which is moderate, and lasts only for half a mile, cannot completely destroy the first impulse. The engine not having been able, during its passage over the obstacle, to acquire a uniform velocity, but continuing on the contrary, to the last moment, to lose some of its speed, showed that that obstacle was too much for it; but the fact, ascertained on a length of 5½ miles, proved that the average inclination of the ascent, or $\frac{1}{1300}$, was within the limits of its power, with a pressure of 55 lbs. per square inch.

This experiment having given rise to some doubts on the real proportions of the Atlas, we measured them ourselves a few days afterwards, on August 8, 1834, when the engine was under repair, and they were found perfectly exact. The diameter of the cylinder is 12 in.; the stroke, measured on the crank of the axletree then separated from the engine, 16 in.; wheels 5 ft., at the part that rests on the rail, with three-eighths of an inch more near the flange, and the three-eighths less at the basiled part.

This experiment, taken on the irregularity of Chatmoss, gives;

lbs.
2,111 power of the engine.
2,226 resistance opposed by the load on the accidental slope at $\frac{1}{800}$.

—155 power minus.

The resistance exceeded the power. It was consequently really impossible for the engine to settle at a uniform velocity, during its passage over the obstacle. It was necessarily compelled to lose constantly of its speed, and would have stopped if the obstacle had lasted any longer.

But, taken on the average rise at $\frac{1}{1300}$, we have:

lbs.
2,111 power.
1,921 resistance of the train, equal to 240 t. on a level.

190 corresponding friction of the engine.

The average velocity during the experiment was 8 miles an hour; the least velocity 3½ miles an hour.

IV. The same engine, on the same day, travelling with the same train over *Rainhill* flat, which is a dead level, attained a uniform velocity of 9.23 miles an hour; the balance fixed at 50 marked 50.5, or effective pressure 53.5 lbs. by the mercurial-gauge.

lbs.
2,054 power.
1,564 resistance of the train, equal to 195½ t. on a level.

490 corresponding friction of the engine.

V. On July 23, 1834, the same engine, the ATLAS, ascended *Sutton* with a part of its train, consisting of 8 wagons, weighing 33.90 t. besides tender, and 39.40 t., tender included; balance fixed at 50 and marking 52, or effective pressure 55 lbs.; velocity 6 miles an hour.

lbs.
2,111 power.
1,594 resistance, equal to 199½ t. on a level.

517 corresponding friction of the engine

VI. On July 24, 1834, the FURY, cylinders 11 in., stroke 16 in., wheels 5 ft., weight 8.20 t., ascended *Whiston* with a train of 10 wagons, weighing together 51.16 t., and 56.16 t. with the tender; balance fixed at 32 and marking 35, or effective pressure by the mercurial-gauge 65½ lbs. per square inch in the boiler; avarage velocity 6.31 miles an hour, reduced to 3.33 miles at the top of the plane.

lbs.
2,114 power.
1,951 resistance, equal to 244 t. on a level.

163 corresponding friction of the engine.

VII. On July 24, 1834, the same engine, the FURY, ascended *Sutton* with a train of 10 wagons weighing 43.80 t., and 48.80 t. including the tender; balance fixed at 32 and marking 36, or effective pressure 67 lbs.; velocity 15 miles an hour. The engine drew its train with evident ease.

lbs.
2,162 power.
1,825 resistance, equal to 228 t. on a level.

337 corresponding friction of the engine.

VIII. On July 31, 1834, the ATLAS, of which the proportions have already been given, cannot ascend *Whiston* with a load of 14 wagons weighing 61.65 t., and 67.15 t. tender included, though the balance had been carried to 57, as point of departure, and marked 60, or effective pressure 63 lbs. per square inch in the boiler.

lbs.
2,419 power.
2,370 resistance, equal to 296¼ t. on a level.

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39 surplus of the power over the resistance, not sufficient to overcome the friction of the engine.

IX. On July 31, the same engine, the ATLAS, cannot ascend *Sutton* with a train of 8 wagons loaded and 4 empty, weighing 35.15 t., and 40.15 t. tender included. The balance had been purposely lowered to 40, as point of departure, and marked 42½, or effective pressure by the mercurial-gauge 46 lbs. per square inch. The velocity from 20 miles an hour, as it was before arriving at the plane, fell immediately to 7½ miles in the first quarter of a mile; in the second quarter it fell to 4¼ miles; in the third to 2¼ miles, and at last the engine stopped.

lbs.
1,766 power.
1,619 resistance, equal to 202⅓ t. on a level.

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147 surplus of power over the resistance, not sufficient, as we see, to overcome the friction of the engine. We have seen that the friction of this engine, even without a load, is 152 lbs.

X. At the conclusion of the latter experiment, and just at the moment when the engine stopped, the balance was raised to 45, and marked 47½, or effective pressure by the mercurial-gauge 51 lbs. With that pressure the engine regained velocity by degrees, and attained a uniform velocity of 7½ miles an hour, with which it reached the top.

lbs.
1,958 power.
1,619 resistance, equal to 202⅓ t. on a level.

---

339 corresponding friction of the engine,

XI. On August 1, 1834, the Vesta, cylinders $11\frac{1}{8}$ in. (this engine had originally cylinders of 11 in., but, in repairing them, they were bored again and acquired a diameter of $11\frac{1}{8}$ in.,) stroke 16 in., wheels 5 ft., weight 8.71 t., with a train of 10 wagons weighing 43.72 t., and 49.22 t. tender included, ascended *Whiston* until within 60 yards of the top. There the engine was on the point of stopping, and several men were obliged to push very hard at the wheels in order to enable it to attain the summit. Balance fixed at $20\frac{1}{2}$, and marking $23\frac{1}{2}$, or effective pressure by the mercurial-gauge 58 lbs. per square inch. The velocity of 20 miles per hour for the first four quarters of a mile of the inclined plane, was reduced to 10 miles for the fifth quarter, and to 6 miles for the following one; afterwards the speed fell completely, on arriving at the steep part that exists towards the top of the inclined plane. This steep part must however be ascended, before it can be said that the engine has gone up the plane; for the average inclination calculated at $\frac{1}{96}$, comprises equally that part, and if we were to separate it from the remainder of the plane, that remainder would have a less inclination than $\frac{1}{96}$: consequently, the load was too much for the engine with that pressure.

lbs.
1,915 power.
1,746 resistance, equal to $218\frac{1}{2}$ t. on a level.

166 surplus of the power over the resistance, insufficient to overcome the friction of the engine. We have seen that the friction of this engine, even without any load, amounts to 187 lbs.

XII. On August 4, 1834, the Atlas, of which the proportions have already been given, with a train of 9 loaded wagons and 7 empty ones, weighing together 38.76 t., and with the tender 44.26 t., could not ascend *Sutton*; the balance being fixed at 55, and marking $57\frac{1}{2}$, or effective pressure $60\frac{1}{2}$ lbs. per square inch in the boiler. That pressure is not sufficient; the engine is ready to stop.

lbs.
2,323 power.
1,755 resistance, equal to 219½ t. on a level.

568 surplus of the power over the resistance, insufficient to overcome the friction of the engine.

This experiment and the following one confine the friction of the engine within very narrow limits; that is to say, between 568 lbs. and 616 lbs., and seem to raise that friction very high; but in referring to experiment No. XI., on the friction of the engines without load, we see that at the time those two experiments were made, the engine had been newly repaired, and was not yet working satisfactorily. On August 1, its resistance, without load, had been found to be 194 lbs., instead of 152 lbs. that it was before, a circumstance which we attributed then to the connecting-rods not being properly adjusted; but the defect seems however to have been more vital, and to have rather continued to increase, as, on August 7, the axle of the engine broke.

XIII. At the conclusion of the foregoing experiment, just at the moment the engine was going to stop, the pressure was raised, by means of the spring, to 58¾ by the balance, or 61¾ lbs. effective pressure per square inch in the boiler by the mercurial-gauge. With that pressure the ascent was concluded, with a speed of 3.75 miles an hour for the upper part of the plane.

lbs.
2,371 power.
1,755 resistance, equal to 219⅓ tons on a level.

616 corresponding friction of the engine.

XIV. On August 4, 1834, the Fury, cylinders 11 in., stroke 16 in., wheels 5 ft., weight 8.20 t., ascended *Sutton* with a first-class train of 8 carriages, amongst which was an empty truck; weight of the train 32.97 t., and with the tender 37.97 t.; pressure purposely reduced to 33 lbs. by

the balance, or 55 lbs. by the mercurial-gauge. Average velocity 13.33 miles, *minimum* velocity 10 miles an hour at the top of the plane.

lbs.
1,775 power.
1,466 resistance, equal to 183¼ tons on a level.

309 corresponding friction of the engine.

XV. On August 15, the LEEDS, cylinders 11 in., stroke 16 in., wheels 5 ft., weight 7.07 t., ascended *Sutton* with 7 wagons, weighing 29.65 t., and tender included 35.15 t. The pressure purposely reduced, stood at 29 by the balance, or 48.5 lbs. by the mercurial-gauge. The velocity of 15 miles an hour for the first mile of the ascent fell to 10 miles for the following quarter, and to 6.6 miles for the last quarter of a mile near the top; average velocity 10 miles.

lbs.
1,565 power.
1,344 resistance, equal to 168 t. on a level.

221 corresponding friction of the engine.

XVI. On August 16, 1834, in the morning the VESTA, the proportions of which have already been given, ascended *Sutton* with a train of 7 loaded wagons, weighing together 34.43 t., and 39.93 t., tender included; the valve fixed at 20, as point of departure, on the balance, and blowing at 23¼, or effective pressure per square inch by the mercurial-gauge 57.25 lbs. Velocity at the top of the plane, 2.50 miles. (The engine had set off on the plane without impulse or acquired velocity.)

lbs.
1,891 power.
1,543 resistance, equal to 193 t. on a level.

348 corresponding friction of the engine.

XVII. On August 16, 1834, in the morning, the same engine ascended *Sutton* with 8 wagons, weighing 31.95 t., and 37.45 t., tender included; balance fixed at 20, as point of departure, and marking 23½, or effective pressure 58 lbs. per square inch in the boiler by the mercurial-gauge. *Minimum* velocity at the moment of attaining the summit of the plane, 3.25 miles.

lbs.
1,915 power.
1,462 resistance, equal to 182¾ t. on a level.

453 corresponding friction of the engine.

XVIII. On August 16, in the evening, the same engine, the VESTA, ascended *Sutton* with 8 loaded wagons, weighing 27.05 t., and 4 empty ones, weighing together 7 t. more the tender, making altogether 39.05 t. Balance fixed at 20 lbs., and marking 23 lbs., or effective pressure per inch 56.5 lbs. by the mercurial-gauge. Velocity at the most difficult point of the ascent, 17 complete strokes of the piston per minute, or 3 miles an hour.

lbs.
1,866 power.
1,514 resistance, equal to 189 t. on a level.

352 corresponding friction of the engine.

SECTION 5.—*Table of the Results obtained on the additional Friction of Engines.*

If, amongst the foregoing experiments, we bring together those that have produced results, we get the following table. We have placed in it only those experiments, the velocity of which was not considerable. It is, indeed, clear that the more the velocity was reduced, the nearer the engine was to attain the proposed end, that is to say, to arrive at the *maximum* load it could possibly draw with its pressure:—

EXPERIMENTS ON THE FRICTION OF LOADED LOCOMOTIVE ENGINES.

Number of the experiment.	Date.	Name of the engine.	Diameter of the cylinder.	Stroke of the piston.	Diameter of the wheel.	Weight of the engine.	Friction without any load.	Effective pressure in the experiment.	Velocity of the experiment.	Load on a level.	Corresponding friction of the engine.	Observations.
	1834.		inches.	inches.	feet.	tons.	lbs.	lbs. per square inch.	miles an hour.	tons.	lbs.	
I - -	July 22	Vulcan	11	16	5	8.34	136	57.5	7.50	188	350	
II - -	July 22	—	11	16	5	8.34	136	57.5	12.00	186	367	
VI - -	July 24	Fury	11	16	5	8.20	109	65.5	3.33	244	163	
XIV -	Aug. 4	—	11	16	5	8.20	109	55.0	10.00	183	309	
XV -	Aug. 15	Leeds	11	16	5	7.07	108	48.5	6.60	168	221	
XVI -	Aug. 16	Vesta	$11\frac{1}{8}$	16	5	8.71	187	57.25	2.50	193	348	
XVII -	Aug. 16	—	$11\frac{1}{8}$	16	5	8.71	187	58.0	3.25	183	453	
XVIII -	Aug. 16	—	$11\frac{1}{8}$	16	5	8.71	187	56.5	3.00	189	352	
III - -	July 23	Atlas	12	16	5	11.40	152	55.0	3.50	240	190	
IV - -	July 23	—	12	16	5	11.40	152	53.5	9.23	196	490	
V - -	July 23	—	12	16	5	11.40	152	55.0	6.00	199	517	
X - -	July 31	—	12	16	5	11.40	152	51.0	7.50	202	339	
XIII -	Aug. 4	—	12	16	5	11.40	194	61.75	3.75	219	616	The connecting-rods keyed too tight.
			Mean				151			200	362	

Considering the average friction deduced from these experiments, we see that a load of 200 t. causes in the engine, above its proper resistance, an *additional* friction of 362 lbs. 362—151 lbs.; which makes 1.05 lbs., or about 1 lb. per ton.

Section 4.—*New illustration of the Mode of Calculation employed.*

The friction of the engines must be increased by the load; for it is a principle in statics, easy to be ascertained in a simple machine like the lever, the pulley, the winch, &c., that for two forces to equilibrate on that machine, the fixed axis, plane, or fulcrum, must support the resulting effect of the two forces. Thus the pressure on the fulcrum is in ratio to that resulting force. If the machine be in motion, we have seen that, as soon as that motion becomes uniform, the power equilibrates exactly the resistance, or the machine falls into the preceding case. Thus again, the pressure on the fixed points is in proportion to the forces that equilibrate on the machine. Consequently, the friction follows the same rule, being itself in proportion to the pressure.

This is applicable to the friction on all the joints of an engine, and consequently to what we call its resistance, which is nothing else but the aggregate of all those frictions.

An increase of resistance, in proportion to the load, is therefore founded on principle, and the mode of calculation we have employed must give us its exact measure. It is sufficient for it that the engine have really attained the limit of its power with a given pressure; that is to say, the *maximum* load it is able to draw with that pressure. In those cases in which the engine reduced its velocity to the rate of two or three miles an hour, it was evident that that point was attained, as the engine was literally going to stop. But, besides, we shall see that in all the cases where the velocity did not exceed 12 miles an hour, we were author-

ized also to consider the pressure on the piston as equal to that in the boiler.

In fact, the steam being at a certain degree of pressure in the boiler, passes into a narrow steam-pipe, and from thence into the cylinder, where it immediately dilates, and would quickly attain the same degree of pressure as in the boiler if the piston was immoveable. However, the piston opposing on the contrary only a limited resistance, determined by the load drawn by the engine, 40 lbs. per square inch for instance, will obey as soon as the elastic force of the steam in the cylinder will have attained that point. A piston which only bears a resistance of 40 lbs. per square inch, is nothing but a valve loaded with 40 lbs. per square inch. If the communication between the boiler and the cylinder were completely free, and without pipe or narrow passage, the piston would become a real valve for the boiler; and that valve giving way before the safety valve, which is loaded, for instance, with 50 lbs. per square inch, the steam in the boiler could not rise above 40 lbs. The passage, however, being narrowed, the piston is not a valve for the boiler, but it remains one for the cylinder.

From this result three points. 1st. That the pressure in the cylinder is exactly equal to the resistance on the piston. 2d. That it is because the piston yields and gives way to the steam that the steam cannot augment its pressure beyond that point, nor rise to the pressure in the boiler; but that if by any means the piston could be rendered immoveable, or only if it were not to give way quicker than the steam is generated, the equilibrium of pressure would immediately be established between the cylinder and the boiler; and, 3d, that if, in the steam-pipe, the velocity of the current is greater than the one corresponding to the generation of the steam in the boiler, it is because the pressure is less in the cylinder than in the boiler, and that in consequence, the fluid endeavours to put itself in equilibrium in the two vessels; without which there could only be the current, owing to the generation of the steam.

From these observations, we see that the effective pressure on the piston may be calculated after that which exists in the boiler, as soon as the velocity of the piston is reduced to an equality with that of the generation of the steam. As we shall soon know by experience what is the total mass of steam, at the pressure of the boiler, generated by the engine in a given instant, it will be easy to calculate how many cylinders full of steam, at that pressure, the engine is able to furnish in a minute, and thus what is the velocity that corresponds to what we call full pressure in the cylinders. We shall then find, that for the engines we are examining, that velocity is at least twelve miles an hour. Thus we may consider that in all the cases in which the velocity did not exceed that rate, the pressure in the cylinder was the same as in the boiler, and, consequently, that in reckoning it in that proportion, we had the exact measure of the power then applied by the engine.

CHAPTER V.

GENERAL THEORY OF THE MOTION OF LOCOMOTIVE ENGINES.

ARTICLE I.

OF THE VELOCITY OF THE PISTON.

In endeavouring to calculate the effect of steam engines, that is to say, the velocity of the piston under a given load, the calculations have until now rested on two *data*, the pressure of the steam in the boiler and the resistance of the load on the piston; one being considered as representing the power exercised by the engine, and the other the resistance opposed by the load.

This mode appears exact at first sight, and seems to embrace all the *data* of the problem; but the mistake committed in that respect ought to have been discovered, since every formula obtained in that way is easily demonstrated false by experience.

It is particularly when we wish to apply that mode or those formulæ to the motion of locomotive engines, in order to calculate what load they are able to draw at a given velocity, or what velocity they will acquire with a given load, that we discover the formulæ give no rational result.

The cause thereof resides in the following fact, viz., that

the pressure of steam in the boiler is by no means the *complete* expression of the power of the engine. It only indicates that power for a determined instant. It is indeed sufficient whenever it is required to compare the effort applied with the effect produced, during a very short instant, or in a case of equilibrium; but as soon as we have a continuation of motion, the pressure in the boiler is no longer sufficient to represent the power of the engine. This is nothing more than what is observed continually in mechanics. In a case of equilibrium, the measure of a force is the mass with which it equilibrates; but in a case of motion, the force is represented not only by the mass it sets in motion, but also by the velocity it is able to impart to that mass. In other words, the force is represented by its own intensity added to the velocity with which it is able to keep up that intensity. The same thing occurs here. The pressure in the boiler indicates the mass with which the engine can equilibrate; but it is the velocity of generation of the steam that indicates the motion the engine is able to impart to that mass.

It is, in fact, evident that the power of the engine resides at the same time, both in the greater or smaller quantity of steam generated, and in the degree of pressure or elastic force of that steam. The power consists thus in the quantity of water the engine is able to transform into steam in a given time, for instance in a minute, which we shall call the evaporating power of the engine, and in the degree of pressure of the steam.

In that valuation we see that the pressure is only the means by which to ascertain the state or intenseness of the power, at the moment its quantity is measured; and this explains the reason why, when the motion is not to last, and that in consequence the quantity need not to be considered, the pressure is sufficient to represent the power. But this is not the case in a continued motion.

When an experiment is to be made with an engine, how-

ever weak it may be in regard to evaporating power, it will be easy, by charging the valve with 50 lbs. per square inch, to fill the boiler with steam at that effective pressure. If then we attach to the engine a load of 100 t. which would produce, by supposition, on the piston, a resistance of 46 lbs. per square inch, atmospheric pressure included; shall we say that the engine must necessarily draw that load with a certain fixed speed, which will only depend on the pressure of steam in the boiler and the resistance on the piston? No, assuredly. For if it should happen that the engine transform in a minute a cubic foot of water into steam at the pressure of the boiler, it may by that evaporation suffice to produce a certain speed; but if, all things remaining the same, it only evaporates half the quantity, it is clear that it will only be able to fill the cylinder half as many times in a minute, and that consequently the pressure in the boiler may remain strictly the same, whilst the speed of the engine with the same load will necessarily be reduced to one half. We see, thus, that neither the pressure in the boiler, nor the supposition that that pressure be maintained in the same state in the different cases of motion, are sufficient to represent completely the power of the engine.

It is thus the evaporation of which the engine is capable that rules its effect, and which must consequently give us the measure of that effect.

If, by analogy with other boilers already tried, and by a comparison of the extent of the heating surfaces, we calculate beforehand what mass of steam a boiler is able to generate in a minute, at a given pressure, we shall then begin to get an idea of the power of which it disposes, and which the engine is able to carry into action.

If, better still, we fill the boiler with water, and produce by some manner or other, in the fire-place, a fire as intense as it generally is when the engine is at work, so that we may thus ascertain its evaporating power, then only shall we know

what the engine, to which we may join that boiler, will be able to execute in a given time.

The pressure in the boiler, taken by itself, can only solve one of the questions we have to consider: that is to say, the greatest load the engine is able to draw, on account of the necessity which exists that the resistance on the piston should never exceed the pressure in the boiler, as in that case the resistance would be greater than the moving power and no motion would be generated. But, that one case excepted, we must necessarily have recourse to the evaporating power, the pressure being only one of the elements of the force which is to be computed. The separate influence of each of those two elements in the result is as follows:

The greatest possible load is marked by the degree of pressure in the boiler.

And the greatest speed with that load, or with any other, is given by the evaporating power.

It is therefore by employing both these elements that we shall be able to solve the question.

With that view we shall successively consider three different points.

The resistance produced on the piston by a given load;

The pressure of the steam in the cylinder in consequence of that resistance;

And, finally, the determination by experiments of the evaporating power of the engines.

These foundations once established, the effect of an engine may easily be calculated by comparing the force of traction the load requires, which fixes the power the engine must expend, with the mass of power of which it is able to dispose; that is to say, its evaporating power.

ARTICLE II.

OF THE RESISTANCE ON THE PISTON OWING TO A GIVEN LOAD.

We have already explained that when a load is attached to an engine, the *total* resistance which is opposed to the motion of the piston is composed, 1st, of the resistance of the load; 2d, of the resistance of the engine; 3d, of the atmospheric pressure. By the same reason the *real* elastic force of the steam is not expressed by its effective pressure, but by its *total* pressure.

In the calculations we have hitherto made, having only to compare the power with the resistance in cases of equality or equilibrium, and without admixture of any other consideration, we were at liberty to deduct on both sides an equal quantity, that is to say, to take into account only the effective pressure, and the effective resistance. But now we shall have to consider the steam in regard to its volume; and, that volume being determined by the *total* pressure, we must keep that expression of the elastic force as well as the one which corresponds with it for the resisting force.

Thus the resistance on the piston is composed of the three resistances, of the load, the engine and the atmosphere. Of these three forces, that which is owing to the atmospheric pressure is exerted immediately and directly on the piston. It must therefore be moved with the same velocity as the piston itself. But with the two others it is different. We have already seen that, in a machine, the pressures produced on different points are in an inverse ratio to the velocity of those points. Here, the engine and its train require to be moved with a velocity greater than that of the piston, in the proportion of the circumference of the wheel to twice the length of the stroke. The intenseness of the pressure pro-

duced on the piston, by the resistance of the load and that of the engine, is therefore greater than those same resistances in the above-mentioned proportion of the velocity of the wheel to that of the piston.

Supposing M to represent the number of tons composing the total load, tender included, and n the resistance per ton, nM will be the resistance of the train. If besides F expresses the friction or resistance of the engine without load, and δ the additional friction per unit of load, F + δ M will be the friction of the engine at the moment it draws the load M.

Thus,

$$F + \delta M + nM$$

will be the resistance opposed to the progress along the rails by the engine and its train.

This force producing on the piston a resistance augmented in the proportion of the circumference of the wheel, to twice the stroke of the piston, if D be the diameter of the wheel, l the length of the stroke, and π the ratio of the circumference to the diameter,

$$(F + \delta M + nM)\frac{\pi D}{2l}$$

will be the resistance on the piston owing to that force; that is to say, to the friction of the engine and its train.

In the same way, representing by d the diameter of the cylinder, $\frac{1}{2}\pi d^2$ will be the area of the two pistons, and

$$\frac{(F + \delta M + nM)\frac{\pi D}{2l}}{\frac{1}{2}\pi d^2}, \text{ or } (F + \delta M + nM)\frac{D}{d^2 l}$$

will be the same force divided over the piston per unit of surface.

Adding to it, therefore, the atmospheric pressure per unit of surface, which we shall represent by ρ, we shall finally have, for the total pressure, owing to the resistance,

$$R = (F + \delta M + nM)\frac{D}{d^2 l} + \rho.$$

In this equation M is the weight of the load in tons, n is equal to 8 lbs. and $\delta = 1$ lb. D, l and d are expressed in inches, F and ρ in pounds; thus the value of R, when found, is the pressure resulting on the piston, in pounds per square inch.

The quantities D, l and d might also be expressed in feet, and ρ in lbs. per square foot. In that case, the value of R, when found, will be the pressure per square foot on the piston. This way of expressing the resistance comes exactly to the same as the preceding one, and is sometimes more convenient for calculation.

Applying this to a load of 100 t., drawn by an engine with cylinders of 11 in. diameter, stroke 16 in., wheel 5 ft., friction 110 lbs., we have,—

100×8 lbs. = 800 lbs. resistance of the train in lbs.
110 lbs. friction of the engine without load.
100 lbs. additional friction, owing to the load.

1010 lbs. total resistance to the progressive motion of the wheels.

3.1416×60 in. = 188.50 in. circumference of the wheel expressed in inches.

2×16 in. = 32 in. double of the stroke.

$\frac{188.5}{32} = 5.887$, ratio of the velocity of the wheel and of the piston.

Thus 1010 lbs. $\times$ 5.887 = 5,946 lbs., resistance produced on the piston.

Besides $\frac{3.1416 \times \overline{11}^2}{2} = 190$ in area of the pistons in square inches.

Thus $\frac{5946 \text{ lbs.}}{190} = 31.2$ lbs. resistance on the piston, divided over each square inch of its surface.

And, lastly, 31.2 lbs. + 14.7 lbs. = 46 lbs. final resistance per unit of surface of the piston of an engine with cylinders of 11 in. diameter, &c. drawing a load of 100 gross tons, tender included.

ARTICLE III.

OF THE PRESSURE IN THE CYLINDER.

The resistance on the piston being known, we may deduce from it the pressure of the steam, at the instant it acts as a moving power in the cylinder. It is sufficient for that to observe what passes during the motion.

The steam, being at first shut up in the boiler at any degree of pressure, passes into the steam-pipes and from thence into the cylinders. When it arrives in those cylinders, the area of which is about ten times as great as that of the pipes, the steam must necessarily expand and lose in the same proportion of its elastic force. However, the pistion is still immoveable; so that the steam continuing to arrive rapidly, the equilibrium of pressure is quickly established between the boiler and the cylinder. The pressure then becomes the same in the two vessels, and the piston, being impelled by the force of the steam, begins slowly to move. The motion is communicated to the engine and to its whole train, and the mass gets a certain speed. This acquired speed continuing a little longer than the cause which produced it, the consequence is, that, at the following stroke, the steam finds the piston already slowly driven in a retrograde direction, at the moment when it gives it a fresh impulse, which in its turn is communicated to the total mass, where it continues to accumulate. Thus, receiving at each stroke a fresh impulse, while it still keeps the preceding one, the piston accelerates, by degrees, its speed, and the train finally acquires all the velocity the engine is able to communicate to it.

We have said that, at the beginning of the motion, an equilibrium of pressure is established between the boiler and

the cylinder ; but, in proportion as the velocity of the piston increases, this piston recedes, in a way, before the steam, without giving it sufficient time to establish the equilibrium, so that the pressure in the cylinder must necessarily diminish.

Nevertheless, the increase of the velocity and the diminution of the pressure have their limits. It is observed in every machine that the speed, at first very small, increases by degrees, as we have said, but only to a certain point which it never passes, the moving power not being capable of a greater speed with the mass to be moved. If the machine is well-constructed, and particularly if it is regulated by a fly-wheel, the velocity once acquired is maintained without alteration, although the action of the moving power may continue to vary or to oscillate between certain limits, and the motion becomes perfectly uniform.

In the engines we consider, the mass of the train itself acts the part of a fly-wheel. That mass receives and stores up in a manner, the additional velocity produced by the moving power at the time of its greatest action, in order to refund it afterwards, whenever the moving power happens to be in a moment of less force. It is from the difficulty of increasing and also of diminishing the speed of the mass, that the uniform motion results.

In regard to certain parts of the engine which, like the piston for instance, must necessarily vary in velocity during their ocillations, the uniformity of which we are speaking, consists in an exact periodical motion, which causes the velocity at each point of an oscillation to be precisely the same as it was at the same point of the preceding one. The result of this is, that if we take the duration of one of these oscillations as the unit of time, the motion will be strictly uniform.

As soon as the motion has acquired uniformity, which always takes place after a very short time and which is the regular state of the engine while travelling, the moving

power, which at the beginning of the motion, was obliged to make an effort necessarily greater than the resistance needs at present only to expend a force just sufficient to keep the resistance in equilibrium. For, if the moving power were to apply a greater or smaller force, the motion would be either accelerated or retarded, whilst, in fact, it is uniform.

From that moment, consequently, the pressure of the steam *in the cylinder*, which is the effort applied by the moving power, must be equal to the pressure of the resistance against the piston, which is the effort made by the resistance. This principle has been already demonstrated less extensively in another place.

We know thus the pressure at which the steam is expended by the cylinder, and as we also know the volume of the cylinder, we shall be able from both to conclude the absolute expense of power which takes place at each stroke of the piston. It is that expense which, compared with the total mass of steam of which the engine can dispose, will give us, without any difficulty, the means of determining the velocity of the motion.

ARTICLE IV.

OF THE EVAPORATING POWER OF THE ENGINES.

Section 1.—*Experiments on the Evaporating Power of the Engines.*

We have yet to determine the chief element of the question, viz. the evaporating power of the engines or the quantity of water they are able to transform into steam, under a determined pressure, in a given time.

With that view we undertook a series of experiments on the quantity of water evaporated by the engines of the Liverpool and Manchester Railway, during their journey from one of those towns to the other.

All the tenders on that railway having exactly the same dimensions and a uniform shape, one of them was weighed, first empty and then loaded, whereby was ascertained that every inch of water in the tank corresponded exactly with a weight of 206.5 lbs. Then we proceeded in the following manner:—

We first ascertained, by means of the glass tube, at what height the water stood in the boiler at the moment of starting; and then we also measured the exact height of the water in the tender. At the end of the journey, or at the intermediate station, if the engine stopped to take in fresh water, we first filled the boiler to the same height where it stood before setting off, and then we measured the water remaining in the tender. The difference between the height in the tender gave the consumption of water during the journey.

When describing these experiments, in order that the reader may see at once before him all the elements that have any importance in the question, we shall give the load

of the engine, the time it took to complete the journey, which shows the velocity, the distance being 29 miles, the state of the spring-balance from which the pressure results, and finally the temperature of the water in the tender at the moment of starting. We shall explain hereafter the column containing the total rising of the valve, which would permit all the steam generated in the boiler to escape.

EXPERIMENTS ON THE EVAPORATING POWER OF THE ENGINES.

Number of the experiment.	Date.	Name of the engine.	Load of the engine, tender included	Water evaporated. In lbs.	Water evaporated. In cubic feet.	Total duration of the journey.	Delays on the road included in that time.	Average state of the spring balance.	Rising of the valve sufficient to give issue to all the steam generated in the boiler.	Average effective pressure during the experiment in lbs. per square inch.	Temperature of the water in the tender at starting.	Velocity of the engine in miles per hour.	Evaporation per hour in each experiment.	Heating surface. Exposed to the action of radiating caloric.	Heating surface. Exposed to the action of communicative caloric.
	1834.		tons.	lbs.	cubic ft.	hours.				lbs.		miles.	cubic ft.	sq. ft.	sq. ft.
I . .	July 22	Vulcan	39.07	4646	74.34	1.17′	3′	31....32.5	5	54.5	just lukewarm	22.99	57.92	34.45	307.38
II . .	July 23	Atlas	195.50	8260	132.16	3.17	15	50....50.7	4	53.7	cold	8.99	40.25	57.06	217.88
III .	Aug. 4	—	127.64	5937	94.99	1.58	0	50....50.1	4	53	cold	15.00	48.30	—	—
IV .	July 31	—	40.15	5524	88.38	1.54	0	24....25.5	4	30	cold	15.53	46.52	—	—
V . .	July 24	Fury	56.16	4878	78.05	1.30	0	31.2....32.6	5	57	cold	19.67	52.03	32.87	307.38
VI .	July 24	—	48.80	5446	87.14	1.35	0	31.2....32.7	5	57	cold	18.63	55.03	—	—
VII .	July 26	Firefly	41.40	6143	98.29	1.40	5	14.5....14.5	3	44	almost cold	17.70	58.97	43.91	362.60
VIII .	July 26	—	41.40	6040	96.64	1.23	5	16.6....17.3	3	49	lukewarm	21.33	69.86	—	—
IX .	Aug. 1	Vesta	33.15	4130	66.08	1.5	0	20. ....21.3	3.5	51	very hot	27.23	61.00	46.00	256.08
X . .	Aug. 15	Leeds	88.34	5989	95.82	1.35	0	31. ....32.2	5	54	just lukewarm	18.63	60.52	34.57	307.38
XI .	Aug. 15	—	37.51	5317	85.07	1.20½	3	26.5....28.5	5	49	very hot	21.99	63.41	—	—
										Means	. . . .	18.88	55.82	43.12	288.35

In those experiments, we have mentioned the state of temperature of the water in the tender, because that circumstance must more or less facilitate the generation of steam, as it is easier to bring to the boiling point water already warm than cold water. However, as the temperature we mark in the tender, exists only at the moment of starting, and as it can remain thus only during a very small part of the journey, which lasts an hour and a half to two hours, it really has but a very inconsiderable influence on the result, of which the above experiments are, besides, a sufficient proof.

We have also set down the pressure under which the steam was generated in each experiment. Water not being able to evaporate under a high pressure, unless by means of a higher temperature, we have reason to suppose that, *cæteris paribus*, the engine must be able to evaporate less water under a more considerable pressure. But as we shall see below, in a table we shall give on the volume and temperature of the steam, that between the degrees of pressure at which the engines constantly work, viz., between 50 and 60 lbs. effective pressure per square inch, the difference of temperature is only 9 degrees by the thermometer, or 4½ degrees difference for the mean pressure, we shall easily be convinced that the influence of the pressure on the quantity of water evaporated must be almost imperceptible. Besides, when we employ a less elevated pressure, the steam generated under that pressure occupies more space, the boiler is too small to contain it, and the valve is consequently more subject to blow. The result is, that the engine-man accustomed to regulate himself by the valve, seeing it continually blow, does not animate his fire so much as in the case where the valve is fixed at a higher pressure. This circumstance, therefore, compensates for the former one, and frequently surpasses it.

We see, consequently, in the related experiments, that the

speed is the only thing that has a constant and perceptible effect on the generation of steam.

The cause of this effect of the speed is, that in those engines the steam, in issuing from the cylinders, is conducted to the chimney, where it creates an artificial current of air, and acts exactly in the same manner as the bellows in giving activity to the fire. Every jet of steam represents a stroke of the bellows; and it is consequently clear, that the more rapid the motion of the engine, the more cylinders of steam will be thrown into the chimney in a minute, and the more violently also will the fire be excited.

By examining the experiments, we find, in fact, that the greater the velocity of the motion, the more considerable was the evaporation; and for that reason it is necessary, in endeavouring to determine the evaporating power of the engines, to take them at their average velocity.

The speed of 18½ miles per hour, which is the average speed of our experiments, fulfils tolerably well that condition for the Liverpool engines. We must, therefore, consider the corresponding evaporation, which was equal to 55.82 cubic feet per hour, as the average evaporation of the engines employed.

Nevertheless, we see that some of those engines have evaporated 60 or 62 cubic feet of water per hour, which makes a cubic foot per minute, or a pound of water per second.

Section 2.—*Of the evaporating Power per unit of heating Surface.*

However, as the different engines that figured in the experiments differed in regard to their heating surface, we can determine precisely the evaporating power only, by comparing the effects of evaporation with the dimensions of the surface which produces them.

That is the object of the two last columns we added to the

preceding table, which repeat the dimensions of the heating surfaces of the engines, so as they were given with more particulars in our first chapter (Chap. I. Art. II. § 3.)

By the mean results of those two columns, we see that the average evaporation of 55.82 cubic feet of water, was produced by a heating surface consisting of 43.12 square feet exposed to the action of the radiating caloric, and 288.35 square feet exposed to the communicative heat. This is, therefore, the extent of evaporating surface to which we must refer the effect produced.

If we admit, in consequence of the experiment related in our first chapter (Chap. I. Art. II. § 3,) that each unit of surface exposed to the communicative heat produces the third part of the effect that same surface would produce if exposed to the radiating caloric, the heating surface above may be represented by 139.24 square feet exposed to the immediate or radiating action of the fire; and as those 139.24 square feet have produced in an hour the evaporation of 55.32 cubic feet, we see that each square foot has evaporated a volume of water expressed by 0.401 cubic foot.

Thus at a velocity of 18½ miles per hour, which is nearly the average speed of the engines, each square foot of heating surface, exposed to the radiating action of the fire, evaporates in an hour a volume of water of 0.401, or a little more than $\frac{4}{10}$ of a cubic foot. This is the expression of the *evaporating power of the engines per unit of heating surface.* Multiplying this, for each engine, by the extent of the heating surface, we shall find the total evaporating power of the engine.

Section 3.—*Of the effective evaporating Power of the Engines.*

We must however remark, that although all that water is transformed into steam, there is only a part of it applied to the working of the engine. To be convinced of this fact,

we need only examine the valves of the engines while working. We see them constantly emit a considerable quantity of steam, which, instead of entering the cylinders, escapes immediately into the atmosphere. This loss is a defect which it would perhaps not be difficult to correct, and, if corrected, would tend considerably towards an enconomy of fuel.

The plan in contemplation on the Liverpool Railway of replacing the present cylinders of the engines by others of a greater diameter, will at least have that advantage, that in case of considerable loads, it will render available all the steam generated in the boiler.

In the experiments of which we have given an account, not only is that loss perceptible, but it is even susceptible of being to a certain degree appreciated.

Under the head "*State of the Spring-balance*," we have inscribed in the table above, according to the observation in each experiment, the point of departure of the spring-balance, and the point at which it rose by blowing. The interval between these two degrees gives the rising of the valve that took place during the experiment, to which rising was owing the escaping of the steam. Thus, in the first experiment, the valve of the Vulcan, fixed at 31 as point of departure, rose to 32½ by the blowing; consequently, the rising of the valve was of 1½ degree on the balance. The same for the others.

In the following column we have given the quantity of rising sufficient for the valve of each of the engines to give issue to all the steam the engines are able to generate. This point may have been already observed in our experiments on the pressure. We have seen, that whatever care be taken to animate the fire, the valve can never rise beyond a certain point, because then it gives issue to all the steam generated. An exact knowledge of this point was easy to acquire by observation in the numerous experiments on the velocity of the engines we are going to relate.

Thus we found, for instance, that the ATLAS engine, travelling at its greatest speed, and stopped all of a sudden, at the instant it was generating the most steam, raised its valve from 50 degrees to 54 degrees; and that the passage resulting from that rising was sufficient to evacuate all the steam. In the same manner, the LEEDS, VULCAN, and FURY, raised in similar circumstances their valve from 31 to 36, VESTA from 20 to 23½, and FIREFLY from 17 to 20; the second valve of these engines being, besides, at the points indicated for them in our experiments on pressure. These degrees of rising naturally depend, 1st, on the quantity of steam generated by each engine, and the diameter of the valve; 2d, on the dimensions of the levers and the size of the divisions of the balance, which makes a degree by the balance correspond with a greater or a lesser rising; and, lastly, on the second valve, which may give more or less issue to the steam.

These circumstances explain the differences that appear to exist between the engines. In the ATLAS, the second valve gave no issue to the steam, and the first was only 2½ in. in diameter; but the divisions of the balance of that engine being very great, on account of the proportions of the lever, four divisions of the balance were equal to a considerable rising of the valve, which was sufficient to evacuate the steam. In the LEEDS, VULCAN, and FURY, the second valve did not rise in the pressures we employed; but the first valve, which is the one we consider here, was 3 in. in diameter. In the VESTA, the second valve gave issue to the steam as well as the first; the consequence of which was, that a rising of 3.5 degrees of the balance was sufficient for the evacuation of the steam. Lastly, in the FIREFLY, only one of the valves blew, but at the time of the experiments that engine was in a very bad condition. Its boiler was leaky, the water ran out into the fire-place, where it evaporated, and a very small quantity of steam was really collected in the boiler.

Repeated experiments having, therefore, determined these

points in a positive manner, it now becomes possible, with the elements we have at our disposal, to appreciate the quantity of steam that escaped during the above-mentioned experiments. It is sufficient for that to compare the two columns, one of which shows the rising that really took place, and the other the rising that would have been sufficient for the evacuation of all the steam. By that means, we shall find that the average rising that took place during the experiments was 12 on 46.5. A quarter of the steam was, therefore, lost through the valve—we might even say a little more, particularly considering that the FIREFLY engine was then in a bad condition—and lost some of its steam through the leaks of its boiler.

On the other hand, that loss of steam is not accidental, but inherent to the construction itself of those engines; and among all the experiments on the velocity that we shall relate below, there will scarcely be found a single instance in which that effect was not produced; and when it was not, the reason was that the fire was not excited to the highest possible degree. It is therefore necessary to establish a distinction between the evaporating power of the engine and what we shall call their *effective* evaporating power; that is to say, the part of that power which is really applied to the working of the engine.

From the experiments above, we find that of all the steam generated in the boiler, three quarters only enter into the cylinders.

Thus, the evaporating power per square foot of heating surface exposed to the radiating caloric, having been found to be 0.401 cubic foot, the available part of it, or the *effective evaporating power expressed in cubic feet of water evaporated in an hour per square foot of surface, is* 0.301 *cubic foot, or* $\frac{3}{10}$ *of a cubic foot.*

Finally, returning to the mean of the above experiments, the evaporating power was in each hour 55.82 cubic feet; consequently, the *effective* evaporating power, taken as an average for all the engines, is 41.87 cubic feet.

ARTICLE V.

OF THE PROPORTIONS OF THE ENGINES, AND THEIR CORRESPONDING EFFECTS.

SECTION 1.—*Analytical expression of the Velocity of the Engine with a given Load.*

With these elements it is easy to determine the velocity which an engine is able to acquire with a given load.

Supposing, for instance, we have a load of 100 t., tender included, attached to an engine with cylinders of 11 in. diameter, stroke 16 in., wheels 5 ft., friction 110 lbs., *effective* pressure of the steam in the boiler 50 lbs. per square inch, and finally effective evaporating power, such as we have found it for the average of the Liverpool engines, ha is to say, 41.87 cubic feet of water evaporated in an hour.

We have already seen above (Chap. V. Art. II.,) that the *total* resistance which that load opposed to the motion of the piston in the case of that engine was 46 lbs. per square inch; and we have also seen that, in consequence of that resistance, the total pressure of the steam, when arriving in the cylinder, was also necessarily 46 lbs. per square inch.

The mass of water evaporated is 41.87 cubic feet per hour, or 0.70 cubic feet per minute. This water is immediately transformed, in the boiler, into steam, at the effective pressure of 50 lbs. per square inch, or the total pressure of 65 lbs. per square inch.

But we know the volume of the steam generated under a determined pressure. Tables of that volume have been formed from experiment, and one will be found below, § 11. According to these tables, the steam, generated under a

total pressure of 65 lbs. per square inch, occupies 435 times the space of the water which produced it. Thus the water transformed into steam at the total pressure of 65 lbs. per square inch, and spent each minute in the motion, formed a volume of

$$0.70 \text{ c. ft.} \times 435 = 304 \text{ cubic feet.}$$

This steam, penetrating into the cylinders, is then reduced to a pressure of 46 lbs. Its temperature, however, remains the same, because the pipes that conduct it to the cylinders and the cylinders themselves are immersed in the boiler, or surrounded by the flame that comes out of the fire-place. We know that the space occupied by the steam, when its temperature remains the same, augments in an inverse ratio to the pressure. At the moment it arrives in the cylinders, that same mass of steam occupies consequently a greater space in the proportion of 65 to 46.

Thus its total volume is then

$$304 \times \frac{65}{46} = 430 \text{ cubic feet.}$$

Now, the area of the two cylinders is 190 square inches or 1.32 square foot; thus the above volume of 430 cubic feet of steam, passing through the cylinders in a minute, must necessarily cross them with a velocity of

$$\frac{430}{1.32} = 326 \text{ feet per minute,}$$

which gives us, consequently, the velocity of the piston in feet per minute with the supposed load.

To deduce from that the speed of the engine in miles per hour, we must observe that an hour contains 60 minutes, and thus that the speed per hour will be 60 times as great; a mile containing 5280 ft., the produce must be divided by that number in order to have the speed expressed in miles; and finally the speed of the engine, according to the proportion of the stroke to the diameter of the wheel, is 5.887 times that of the piston.

We shall consequently have

$$\frac{326 \times 60}{5280} \times 5.887 = 21.83 \text{ miles, velocity of the engine per hour.}$$

Thus we see that the evaporation supposed above, must necessarily produce a velocity of $21\frac{3}{4}$ miles per hour for the engine; that is to say, that a locomotive engine, with the above-mentioned proportions, is able, if in a good condition and with a well-animated fire, to draw a load of 100 t., tender included, with a velocity of $21\frac{3}{4}$ miles an hour.

The same mode of calculation may serve for any other load or any other engine. Thus, in general, making again use of the letters already employed in our research of the resistance on the piston, viz.

M representing the number of tons of the load.

n the resistance of the load per ton.

F the friction of the engine without load.

δ its additional friction for each ton of the load.

D the diameter of the wheel.

d the diameter of the cylinder.

l the length of the stroke.

And p the atmospheric pressure per unit of surface.

$$R = (F + \delta M + nM)\frac{D}{d^2 l} + p,$$

will be the pressure of the steam per unit of surface in the cylinder as above demonstrated (Chap. V. Art. II.)

If, besides,

P express the total pressure of the steam in the boiler;

s, the effective evaporating power of the engine expressed by the number of cubic feet the boiler is able to evaporate in a minute at the pressure P,

And m the ratio of the volume of the steam, at the degree of pressure P, to the volume of water,

$$m \times s$$

will be the total volume of steam generated in a minute at the pressure P of the boiler.

The steam, arriving in the cylinder, passes from the pressure P to the pressure R, and changes its volume in an inverse ratio to the pressures; so that

$$ms \times \frac{P}{R}$$

is the space occupied by the steam when arrived in the cylinders.

This volume of steam, crossing the cylinders in a minute, if we divide it by the area of the cylinders, we shall have the speed it must necessarily have, and consequently the velocity it will communicate to the piston.

Now the area of the two cylinders is $\frac{1}{2}\pi d^2$; thus the velocity per minute will be,

$$\frac{ms\,P}{\frac{1}{2}\pi d^2\,R}.$$

In order to effect that division, the area of the cylinders ought necessarily to be expressed in units similar to those of the volume s. The area of the cylinders must be then expressed in square feet and not in inches; and the same condition is consequently required also for R, P, and ρ. So in the calculation we must express the pressures in lbs. per square foot, which puts them at the same rate as if expressed in the usual manner.

Passing from this expression to the velocity of the engine, we know that it is to the velocity of the piston in the proportion of the circumference of the wheel to twice the stroke, thus the speed of the engine is

$$v = \frac{ms\,P\,D}{R\,d^2\,l};$$

or putting for R its value found above, and passing from the speed per minute to the speed per hour, in multiplying by 60,

$$V = 60\,\frac{ms\,P\,D}{(F + \delta M + nM)\,D + \rho\,d^2 l}$$

It must be remarked that 60 s is equal to S, or the evapo-

rating power *per hour*; that is to say, that by employing this value it is no longer necessary to multiply by 60, and the reckoning will be simplified in its application.

The formula will then be,

$$V = \frac{m \text{ P S D}}{[\text{F} + (\delta + n) \text{ M}] \text{ D} + \rho d^2 l}$$

This will consequently be the general expression of the velocity of the engine per hour; expression in which every thing is known by measures taken on the engine, even the evaporating power S, which results from the extent of the heating surface computed as above. m, which is the volume of the steam generated under the pressure P, is found in a table like the one below (Chap. V. Art. V § 11.)

By means of this formula, and by measures simply taken on the engine, it will therefore be easy to determine immediately the effect we may expect from it.

In that expression, the evaporating power S being expressed in cubic feet, the resulting speed will also be expressed in feet. If we wish to have it in miles, as a mile contains 5280 ft., it will be sufficient to divide by that number, and the result will be the speed of the engine in miles per hour.

We shall see farther on that the produce mP is almost invariable; and consequently we learn by the inspection of this formula, that the velocity of an engine with a given load increases with the heating surface and the diameter of the wheel, and diminishes, on the contrary, when the diameter of the cylinder and the stroke of the piston augment.

Section 2.—*Analytical expression of the Load that an Engine can draw at a given Velocity.*

If, on the contrary, we wish to know the load a given engine can draw at a determined speed, it is sufficient, in the foregoing equation, to consider V as known and to draw from it the unknown quantity M.

It will then be,

$$M = \frac{m\,P\,S\,D - \rho\,d^2 l\,V}{(\delta + n)\,V\,D} \quad \frac{F}{\delta + n}.$$

After the manner that the calculation has been established, it is clear that the value we shall find for M, will be the number of tons of the *total* load, that is to say, tender included.

Section 3.—*Of the Heating Surface that must be adopted to obtain from an Engine a determined Velocity with a given Load.*

The same equation may also serve to determine any one of the indeterminate quantities in the general problem of locomotive engines. Thus, for instance, it will show the extent of heating surface, or the evaporating power necessary to enable an engine to draw a known load at a fixed speed. For that, we have only to draw from the general equation the value of S.

It will be,

$$S = \frac{V\,[(\delta + n)\,M\,D + F\,D + \rho\,d^2 l]}{m\,P\,D}.$$

The result thus obtained will be the effective evaporating power of the engine in cubic feet of water per hour; and as we have seen (Chap. V. Art. IV. § 3) that the effective evaporating power is equal to $\frac{3}{10}$ of the heating surface expressed in square feet, we shall easily obtain the last by multiplying the result by the fractional number $\frac{10}{3}$.

Section 4.—*Of the Maximum Load of an Engine with a given Pressure.*

We found above (§ 2) the expression of the load an engine is able to draw at a given velocity; and the less the velocity, the more considerable may be the load. We must, however, add that in all cases, for the motion to be possible,

the resistance on the piston must not be greater than the force that is to move it. Consequently, the resistance we have expressed by R, must, at most, be equal to P. This observation fixes the limits of the possible load, with a determined pressure. Beyond that point the equation may continue to give results, but they will no longer suit the question. The limit of the load with the pressure P will thus be known by the equation R = P; or,

$$[F + (\delta + n) M] \frac{D}{d^2 l} + \rho = P,$$

which gives

$$M = \frac{(P - \rho) d^2 l}{(\delta + n) D} - \frac{F}{\delta + n}$$

This equation will give the maximum load of the engine, including the weight of the tender, subservient, however, to the conditions of adhesion explained hereafter, in Chapter VIII.

Section 5.—*Of the Velocity of the Engine corresponding with the Maximum Load.*

Putting that value of M in the formula that gives the speed, we have the speed corresponding with the maximum load. After the necessary reductions we find—

$$V = \frac{m S D}{d^2 l}.$$

If we write this expression under the following form—

$$V = \frac{m S}{\frac{1}{2} \pi d^2} \times \frac{\pi D}{2 l},$$

we shall perceive, at first sight, that it is exactly the speed produced by the passage in the cylinders of the steam of the boiler, when that steam undergoes no reduction of pressure. In fact, $\frac{m S}{\frac{1}{2} \pi d^2}$ is the mass of steam produced *at the pressure of the boiler*, divided by the area of the two cylinders; that is to say, the speed which its passage in the cylinders, without

alteration, produces for the piston; and multiplying that quantity by $\frac{\pi D}{2l}$ which is the proportion of the velocity of the engine to that of the piston, the result will naturally be the relative speed of the engine.

We also see that in the case of a *maximum* load, the pressure of the steam in the cylinder will be the same as in the boiler, and that its velocity will be the very velocity at which the steam is generated in the boiler; results which besides are, of themselves, evident to an attentive mind, and which have already been pointed out.

In regard to the limit of speed with small loads, the engine-men never urge it so as to risk an accident, by too great a velocity in the motion of the piston, or other parts of the mechanism. Only one single instance, in the experiments we shall relate below, will be found, in which the engines attained a speed of 35 miles an hour. This velocity is the greatest that has been observed, until the present moment, except during some extremely short intervals. When the train is too light, the engine-men take care partially to shut the regulator, and not to animate the fire to its highest pitch, as we shall mention hereafter.

Section 6.—*Of the Diameter that ought to be given to the Cylinder, to render an Engine capable of attaining a fixed Maximum Load.*

The same equation from which we have concluded above (§ 4) the limit of possible loads with a given pressure, may also serve to determine the diameter that ought to be given to the cylinders of an engine to render it capable of drawing a fixed load at a certain pressure, viz:

$$d = \sqrt{\frac{D\,[(\delta + n)\,M + F]}{(P - p)\,l}}.$$

This diameter will be expressed in feet, according to the

manner the calculation was made. It will be easily reduced to the common expression in inches.

Section 7.—***Of the Length that ought to be given to the Stroke of the Piston of an Engine, the Cylinders of which have already a fixed Diameter, so as to enable that Engine to draw a certain Maximum Load.***

In the same manner, also, if the diameter of the cylinder has already been chosen on account of some other consideration, we may, in a certain degree, produce the same effect; that is to say, render the engine able to attain the maximum load required, by adopting for the stroke of the piston a suitable length. In that case the equation gives—

$$l = \frac{D\,[(\delta + n)\,M + F]}{(P - \rho)\,d^2}.$$

This measure of the stroke will be expressed, according to the adopted measures, in feet and decimals of feet; one may transform it, as usual, in inches.

Section 8.—*Of the Diameter that ought to be given to the Wheel of an Engine, so as to enable it to draw a fixed Maximum Load.*

We may also obtain the same result by reducing, in a suitable proportion, the diameter of the wheel, by which the speed of the engine will be diminished, and a greater power of traction given to it. The equation will, in that case, give for the diameter of the wheel—

$$D = \frac{(P - \rho)\,d^2 l}{(\delta + n)\,M + F}.$$

It is understood that this method can only succeed within certain limits, and that the diameter of the wheel cannot be reduced beyond certain dimensions, fixed by the other requisites of the business.

Section 9.—*Of the effective Pressure necessary in the Boiler of an Engine, the Dimensions of which are already fixed, in order that the Engine may draw a certain Maximum Load.*

Finally, if the length of the stroke, the diameter of the cylinders, and that of the wheel, are already fixed, we may calculate what is the pressure that must be produced in the boiler to enable the engine to attain the maximum load required. The same equation resolved in that case, in regard to the quantity P considered as unknown, gives—

$$P - p = \frac{D\,[(\delta + n)\,M + F]}{d^2 l}.$$

This pressure will be expressed, according to the adopted measures, in pounds per square foot, but, by taking the $\frac{1}{144}$ part of it, we may reduce it to the usual expression of pounds per square inch.

The same would take place in regard to any other research. These deductions are easily found;—we shall not stop any longer on this point. It is scarcely necessary to add, that the values given by those equations are only applicable to the questions, in as far as they are not in opposition to the practical rules of construction. Thus, the pressure determined above must in no case exceed the resistance of which the metal of the boiler is capable; neither must the diameter of the wheel be large enough to put the engine in danger of going off the rails, nor small enough to destroy its speed, &c. &c.

Section 10.—*Synoptical Table of the preceding Formulæ.*

In a view to facilitate practical researches, we shall collect here those different formulæ into a table.

The signs employed having the following significations, viz:—

M, representing the number of gross tons of the load, tender included.

n, the resistance per ton of the load, or according to the determination already made, $n = 8$ lbs.

F, the friction of the engine without load, taken, according to the average of the above experiments, in case the engine is not yet constructed; that is to say, at 15 lbs. per ton of its presumed weight. In case the engine is already constructed, and one wishes to obtain a very accurate result, F must be determined by a direct experiment made on the engine itself.

δ, the additional friction of the engine per ton of load, or according to the determination hereabove, $\delta = 1$ lb.; and, consequently, $(\delta + n) = 9$ lbs.

D, the diameter of the wheel expressed in feet.

d, the diameter of the cylinder, also expressed in feet and decimals of feet.

l, the length of the stroke, in feet and decimals of feet.

P, the *total* pressure (or atmospheric pressure included) of the steam in the boiler, expressed in pounds per square foot; that is to say, 144 times the pressure per square inch.

p, the atmospheric pressure expressed in pounds per square foot as above, that is to say, $p = 2117$ lbs.; and, consequently $(P - p,)$ the effective pressure of the steam in the boiler, being expressed in the same manner, viz., in pounds per square foot.

S, being the *effective* evaporating power of the engine per hour, or otherwise, according to the described experiments, S being the $\frac{3}{10}$ of the number of square feet in the *reduced* heating surface. (It will be recollected, that the *reduced* heating surface itself consists of the sum of the heating surface of the fire-place, more the third part of the heating surface of the tubes.)

m, being the ratio of the volume of the steam at the *total* pressure P, to the volume of water that has produced it,

according to the known tables, one of which will be found in one of the following paragraphs.

V, finally, being the velocity of the engine in feet per hour, that velocity being necessarily expressed in that manner for the general harmony of the calculation; but as a mile contains 5280 feet, it can easily be reduced to the speed in miles, and *vice versa*.

These different signs being thus well understood, and the letters n and δ being replaced by their values, 8 lbs. and 1 lb., the formulæ above give the following table :—

SYNOPTICAL TABLE OF THE PRACTICAL FORMULÆ OF LOCOMOTIVE ENGINES.

QUESTIONS TO BE SOLVED.	FORMULÆ.
1. *Velocity* which an Engine of known proportions will take, when working at a given pressure, and drawing a determined load. The result being the speed in feet per hour, the speed in miles will be obtained by dividing by 5280:—	$V = \dfrac{m\,P\,S\,D}{(F + 9\,M)\,D + \rho d^2 l}$.
2. *Load* that a given Engine will be able to draw, with a known pressure, and at a determined velocity. This load will be expressed in gross tons, tender included:—	$M = \dfrac{m\,P\,S\,D - \rho a^2 l V}{9\,V\,D} - \dfrac{F}{9}$,
3. *Heating Surface* that must be given to the boiler of an Engine, in order that it may draw a known load with a fixed velocity. The equation gives the effective evaporating power per hour, from which the heating surface may be deduced by multiplying by the fractional number $\frac{10}{3}$:—	$S = \dfrac{V\,[\,(9M + F)\,D + \rho d^2 l\,]}{m\,P\,D}$.

SYNOPTICAL TABLE OF THE PRACTICAL FORMULÆ OF LOCOMOTIVE ENGINES.

QUESTIONS TO BE SOLVED.	FORMULÆ.
4. *Maximum load* that an Engine is able to draw at a determined pressure. This load is expressed in gross tons, and includes the tender:—	$M = \frac{(P-\rho)\, d^2 l}{9D} - \frac{F}{9}$.
5. *Velocity* of an Engine with its *maximum* load. This speed being expressed in feet, the speed per mile will be its $\frac{1}{5280}$ part:—	$V = \frac{m\, S\, D}{d^2 l}$.
6. *Diameter* that must be given to the *cylinder* of an Engine not yet constructed, in order that, if necessary, it may draw a certain maximum load. The diameter being expressed in feet and decimals of feet, its expression in inches will be found in multiplying by 12:—	$d = \sqrt{\frac{D\,(9M + F)}{(P-\rho)\, l}}$.

SYNOPTICAL TABLE OF THE PRACTICAL FORMULÆ OF LOCOMOTIVE ENGINES.

QUESTIONS TO BE SOLVED.	FORMULÆ.
7. *Length of Stroke of the Piston* that may replace the diameter of the cylinder, and produce the same effect of maximum load. This stroke will be expressed in feet, and may be transformed into inches, as above:—	$l = \frac{D\,(9\,M + F)}{(P - \rho)\,d^2}$.
8. *Diameter of the wheel* of an Engine, in order to render it able to draw the same maximum load:—	$D = \frac{(P - \rho)\,d^2\,l}{9\,M + F}$.
9. *Effective pressure* that must be produced in the boiler of a given Engine, in order to render that Engine capable of drawing a certain maximum load. This pressure being expressed in pounds per square foot, the pressure per inch will be its $\frac{1}{144}$.	$(P - \rho) = \frac{D\,(9\,M + F)}{d^2\,l}$.

We must remark that these formulæ are not such as are called *empiric* ones; that is to say, imaginary suppositions, corresponding more or less exactly with experience. They are, on the contrary, rigorous deductions from the most solid principles of mechanics; their elements have been determined by direct experiments, and their results will soon be confirmed in the same way.

In all cases, these formulæ suppose the engine drawing its load *on a dead level.* If it be required to apply them to the case of an inclined plane, it will suffice to take for M, not the nominal load of the engine, but its real load; that is to say, not merely the resistance of the wagons, but their resistance *in ascending the inclined plane in question,* as will be seen in Chap. VII. Art. II.

Section 11.—*Table of the Volume of the steam generated under different degrees of Pressure, necessary for the application of the Formulæ.*

The use of the formulæ we have obtained, necessitating a knowledge of the volume of the steam at different degrees of pressure, we subjoin here a table which we have calculated from 5 to 5 lbs. pressure. The intermediate degrees may be easily filled up: but it would be an unnecessary operation, as we shall see that the pressure in the boiler has so little influence on the speed, that we may, in our calculations, take from the table the pressure nearest to the one we require, provided also we take the volume corresponding with that approximate pressure.

The reason of the little influence the pressure has on the result is, that in proportion as the pressure augments, the volume of the steam diminishes, so that the produce mP, that the equation contains, remains constant for such values of P as are very near to each other. We shall very shortly be witnesses of that fact, which will be explained in the calculation we shall make of the velocity of the engine at different pressures.

TABLE OF THE VOLUME OF STEAM GENERATED UNDER DIFFERENT PRESSURES.

Total pressure expressed.		Corresponding temperature by Fahrenheit's thermometer.	Volume of the steam compared to the volume of the water that produced it.
In lbs. per squre inch.	In atmospheres		
lbs.		degrees.	
15	1.021	212.6	1,670
20	1.361	227.9	1,282
25	1.701	240.3	1,044
30	2.041	250.8	883
35	2.381	260.0	767
40	2.721	268.1	678
45	3.061	275.4	609
50	3.401	282.0	553
55	3.742	288.1	506
60	4.082	293.8	468
65	4.422	299.1	435
70	4.762	304.0	407
75	5.102	308.7	382
80	5.442	313.1	360
85	5.782	317.3	341
90	6.122	321.3	324
95	6.463	325.1	308
100	6.803	328.8	294

SECTION 12.—*Of the combined Proportions that ought to be given to the parts of an Engine, in order that it may fulfil several conditions at the same time.*

We have given, above, separate from each other, the different practical formulæ of locomotion; but we may also combine those formulæ with one another. To give an example of this, and at the same time a practical application of the results obtained hitherto, we shall suppose that it is required to build an engine capable of drawing a certain given maximum load, and, at the same time, capable of attaining a certain speed, with another load also known.

In this case we may determine the diameter of the cylin-

der, according to the first condition; and the heating surface of the boiler according to the second.. Letting, therefore M′ be the given maximum load, M″ the second load mentioned above, and V″ the velocity of the engine corresponding with that second load, we shall have simultaneously the two following equations:—(See § 6 and 3.)

$$d = \sqrt{\frac{D\,(9\,M' + F)}{(P - \rho)\,l}}$$

and

$$S = \frac{V''\,[(9 \times M'' + F)\,D + \rho\,d^2\,l]}{m\,P\,D}.$$

The first equation will give the diameter of the cylinder; and then, introduced in the second equation, it will fix the wanted value of S.

This case is evidently that of a railway on which it would be required that the average trains should have on a level a certain regular speed, and that, at the same time, the engines might ascend with those trains, and without any extra help, an acclivity occurring on a point of the road.

Let us then suppose that it is wanted to build an engine with coupled wheels, capable of drawing a train of 100 gross tons, at a speed of 20 miles an hour on a dead level; and that it is required, at the same time, that that engine be able to ascend without extra aid, and with the same load (reducing, however, its speed,) a plane inclined in the proportion of $\frac{1}{200}$.

We know that an engine working upon a level undergoes, from its load, a certain degree of resistance, which proceeds from the friction of the wagons; but in going up an inclined plane, the load presents not only that same friction of the wagons, but also a surplus of resistance proceeding from the tendency of the train to roll back towards the foot of the plane. The force that draws the train backwards, depends on the weight of the train and on the inclination of the plane. It is the gravity along the plane, and is equal to the mass

that is to be moved, divided by the number that marks the inclination of the plane.

On an inclination of $\frac{1}{200}$, the gravity of a weight of 112 t., which is the weight of the train and engine together, is in pounds.

$$\frac{112 \times 2240}{200} = 1254 \text{ lbs.}$$

Now, 1254 lbs., at the rate of 9 lbs. per ton (including the increase of friction in the engine,) represents the resistance of $\frac{1254}{9} = 139$ t. *on a dead level.* The surplus of resistance occasioned by the inclination of the plane is, therefore, equal to the traction of 139 t. on a level. Consequently, the *total* traction on the rising ground will be 139 t. + 100 t. = 239 t.

Thus, in this case, the load on the inclined plane will be - - - . . - - $M' = 239$ t.
And the load on the dead level - - - $M'' = 100$ t.,

The engine being supposed to weigh 12 t., with coupled wheels, will have a friction of about 180 lbs. If, besides, we suppose it to have a wheel of 5 feet, with a stroke of 16 in. or 1.33 ft.; and if we wish the effective pressure $(P - p)$ in the boiler, during the ascent, not to exceed 60 lbs. per square inch, or, in other words, 8640 lbs. per *square foot,* the first equation will give, for the diameter of the cylinder—

$$d = \sqrt{\frac{5\,(9 \times 239 + 180)}{8640 \times 1.33}} = 1 \text{ foot.}$$

Thus the cylinder must have 1 ft. or 12 in. in diameter.

This value must be introduced in the second equation with the other data of the problem. Observing, moreover, that during the journey one may reduce the effective pressure in the boiler to 50 lbs. (or 65 lbs. total pressure) per square inch, which gives for the corresponding volume of the steam $m = 435$ (see the table given in the preceding paragraph,) the second equation will give—

$$S = 20 \times 5280 \frac{(900 + 180)\,5 + 2117 \times 1.33}{435 \times (65 \times 144) \times 5} = 42.65.$$

By which we see that the effective evaporating power S' of the engine must be 43 cubic feet of water per hour. And, as we know, by the experiments related above, that the effective evaporating power is equal to $\frac{9}{10}$ of the reduced heating surface, this surface must be $43 \times \frac{10}{9} = 143$ square feet.

Finally, this last condition will be fulfilled by giving, for instance, to the fire-place a heating surface of 50 square feet, and to the tubes a surface of 280 square feet.

This example indicates sufficiently the manner in which the calculation is to be made. It would be the same with any other combination that might occur. Evidently, nothing is required but to bring together the different equations concerning the different unknown quantities, and to express that they exist simultaneously.

ARTICLE VI.

PRACTICAL TABLES OF THE PROPORTIONS AND EFFECTS OF THE ENGINES.

Section I.—*A Practical Table of the Diameter of the Cylinder and Pressure of Steam, necessary to enable a Locomotive Engine to draw a given Maximum Load.*

We have just calculated, in a special case, the diameter necessary for the cylinder of an engine working at a given pressure, so that it may draw a certain maximum load. In continuing the same calculation through a series of different cases, after the formula § 6, we form the following practical table, which will show either the diameter of the cylinder when the pressure is given, or the pressure in the boiler, when it is the diameter of the cylinder which is determined,

or, finally, the maximum load when the two other *data* are fixed beforehand.

It must be understood that the engines will not be able to draw the loads marked in the table, unless the rails are in such a state as to offer a sufficient adhesion to the wheels; without which condition, the movement could not be effected, as will be explained in Chap. VIII.

A PRACTICAL TABLE OF THE DIAMETER OF THE CYLINDER AND PRESSURE OF STEAM CORRESPONDING TO GIVEN MAXIMUM LOADS.

Description of the Engine.	Max. load in gross tons, tender includ.	Diameter of the cylinder, in inches, the pressure per square inch in the boiler being				
		50 lbs.	55 lbs	60 lbs.	65 lbs.	70 lbs.
	tons.	in.	in.	in.	in.	in.
Engine with wheel, - - 5 ft.	100	8.8	8.4	8.0	7.7	7.4
Stroke of the piston 16 in. or 1.33 ft.	125	9.7	9.2	8.8	8.5	8.2
	150	10.5	10.0	9.6	9.2	8.9
Weight - - - 8 tons.	175	11.3	10.8	10.3	9.9	9.5
or presumed friction 120 lbs.	200	12.0	11.5	11.0	10.5	10.2
	225	12.7	12.1	11.6	11.1	10.7
	250	13.4	12.7	12.2	11.7	11.3
Engine with wheel - - 5 ft.	200	12.2	11.6	11.1	10.7	10.3
Stroke of the piston 16 in. or 1.33 ft.	225	12.9	12.3	11.8	11.3	10.9
	250	13.5	12.9	12.3	11.9	11.4
Weight - - - 12 tons.	275	14.1	13.5	12.9	12.4	11.9
or presumed friction 180 lbs.	300	14.7	14.0	13.4	12.9	12.4
	325	15.3	14.6	14.0	13.4	12.9
	350	15.8	15.1	14.4	13.9	13.4
Engine with wheel - - 5 ft.	200	11.5	10.9	10.5	10.0	9.7
Stroke of the piston 18 in. or 1.50 ft.	225	12.1	11.5	11.0	10.6	10.2
	250	12.7	12.1	11.6	11.1	10.7
Weight - - - 11 tons.	275	13.3	12.7	12.1	11.6	11.2
or presumed friction 165 lbs.	300	13.8	13.2	12.6	12.1	11.7
	325	14.4	13.7	13.1	12.6	12.1
	350	14.9	14.2	13.	13.0	12.6

Section 2.—***A Practical Table of the length of Stroke of the Piston, and Diameter of Wheel, necessary to enable an engine to draw a fixed Maximum Load at a given Pressure.***

In solving the formula § 7, in a series of cases adapted to the engines the most in use, the following table is formed, which will show, at first sight, either the length of stroke of the piston, or the diameter of the wheel which an engine ought to have, for it to draw a maximum load at a given pressure; or, again, the maximum loads corresponding to given dimensions for the length of stroke of the piston and diameter of the wheel.

A PRACTICAL TABLE OF THE LENGTH OF STROKE AND DIAMETER OF WHEEL, CORRESPONDING TO GIVEN MAXIMUM LOADS.

Description of the Engine.	Max. load in gross tons, tender incld.	Length of stroke in inches, the diameter of the wheel being 3 ft.	4 ft.	5 ft.	6 ft.
	tons.	in.	in.	in.	in.
Engine with cylinders 11 in. or 0.917 ft.	150	8.7	11.7	14.6	17.5
Weight . . . . . . 8 tons,	175	10.1	13.4	16.8	20.2
or presumed friction 120 lbs.	200	11.4	15.2	19.0	22.8
Effective pressure per sq.	225	12.8	17.0	21.3	25.5
inch in the boiler . 50 lbs.	250	14.1	18.8	23.5	28.2
Engine with cylinders 12 in. or 1 ft.	200	9.8	13.0	16.3	19.5
Weight . . . . . . 10 tons.	225	10.9	14.5	18.1	21.8
or presumed friction 150 lbs.	250	12.0	16.0	20.0	24.0
Effective pressure per sq.	275	13.1	17.5	21.9	26.3
inch in the boiler . 50 lbs.	300	14.3	19.0	23.8	28.5
Engine with cylinders 13 in. or 1.083 ft.	200	8.4	11.2	14.0	16.8
Weight . . . . 11 tons.	225	9.3	12.5	15.6	18.7
or presumed friction 165 lbs.	250	10.3	13.7	17.2	20.6
Effective pressure per sq.	275	11.3	15.0	18.8	22.5
inch in the boiler . 50 lbs.	300	12.2	16.3	20.4	24.4
	325	13.2	17.6	22.0	26.4
	350	14.1	18.8	23.6	28.3
Engine with cylinders 14 in. or 1.166 ft.	250	8.9	11.9	14.9	17.9
Weight . . . . . . 12 tons.	275	9.8	13.0	16.3	19.5
or presumed friction 180 lbs.	300	10.6	14.1	17.7	21.2
Effective pressure per sq.	325	11.4	15.2	19.0	22.8
inch in the boiler . 50 lbs.	350	12.3	16.3	20.4	24.5
	375	13.1	17.4	21.8	26.2
	400	13.9	18.5	23.2	27.8

SECTION 3.—*A Practical Table of the Area of Heating-Surface capable of producing a given Velocity with given Loads.*

In order to facilitate practical researches, we shall extend, to a certain number of the most ordinary cases, the calculation of the heating surface capable of producing predetermined effects.

The table which we are thus going to form after the formulæ in § 3, may serve, not only to determine the heating surface capable of producing desired effects, but also the velocity of given loads, when the heating surface is already determined.

The table supposes the engine working at 50 lbs, effective pressure, per square inch, in the boiler. As, however, the pressure has no perceptible influence on the velocity, as will be seen hereafter, if the engine works at a higher pressure, it will be able to attain a more considerable maximum load; but for all the loads of the table, it will, nevertheless, require the same heating surface in order to produce the same velocity. In consequence, the table may serve for any pressure, either above or below 50 lbs. The only difference will be in the maximum loads, which, agreeably to the pressure, will be greater or smaller than those fixed in the table.

By recurring to § 10 of the preceding Article, it will be seen in what manner the area of heating-surface is to be computed.

A PRACTICAL TABLE OF THE HEATING-SURFACES CAPABLE OF PRODUCING A GIVEN VELOCITY WITH GIVEN LOADS.

Description of the Engine.	Load in gross tons, tender includ.	Area of heating-surface of the boiler in square feet, the desired velocity in miles per hour being				
		10 miles.	15 miles.	20 miles.	25 miles.	30 miles.
	tons.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.
Engine with wheel . . 5 ft.	25	36	54	71	89	107
Stroke of the piston 16 in. or 1.33 ft.	50	46	68	91	113	136
Cylinders 11 inches, or 0.917 ft.	75	55	83	110	138	165
Weight . . . 8 tons.	100	65	97	130	162	194
or presumed friction 120 lbs.	125	75	112	149	186	223
Effective pressure per	150	84	126	168	210	252
sq. inch in the boiler 50 lbs.	165	90	135	180	225	—
Engine with wheel . . 5 ft.	50	51	76	101	126	151
Stroke of the piston 16 in. or 1.33 ft.	75	60	90	120	150	180
Cylinders 12 inches, or 1 ft.	100	70	105	140	175	210
Weight . . . 10 tons.	125	80	120	159	199	239
or presumed friction 150 lbs.	150	90	134	179	223	268
Effective pressure per	175	99	149	198	248	297
sq. inch in the boiler 50 lbs.	196	107	161	215	268	—
Engine with wheel . . 5 ft.	50	56	83	111	138	166
Stroke of the piston 16 in. or 1.33 ft.	75	65	98	130	163	195
Cylinders 13 inches, or 1.083 ft.	100	75	112	150	187	224
Weight . . . 11 tons.	125	85	127	169	211	253
or presumed friction 165 lbs.	150	94	141	188	235	282
Effective pressure per	175	104	156	208	260	—
sq. inch in the boiler 50 lbs.	200	114	171	227	284	—
	225	124	185	247	—	—
	231	126	189	251	—	—
Engine with wheel . . 5 ft.	50	61	91	121	151	181
Stroke of the piston 16 in. or 1.33 ft.	75	70	106	141	176	211
Cylinders 14 inches, or 1.166 ft.	100	80	120	160	200	240
Weight . . . 12 tons.	125	90	135	180	224	269
or presumed friction 180 lbs.	150	100	149	199	249	298
Effective pressure per	175	109	164	218	273	—
sq. inch in the boiler 50 lbs.	200	119	178	238	297	—
	225	129	193	257	—	—
	250	139	208	277	—	—
	269	146	219	291	—	—
Engine with wheel . . 5 ft.	50	62	92	123	153	184
Stroke of the piston 18 in. or 1.50 ft.	75	71	107	142	178	213
Cylinders 12 inches, or 1 ft.	100	81	121	162	202	242
Weight . . . 11 tons.	125	91	136	181	226	271
or presumed friction 165 lbs.	150	100	151	201	251	301
Effective pressure per	175	110	165	220	275	—
sq. inch in the boiler 50 lbs.	200	120	180	239	299	—
	221	128	192	256	—	—

Section 4.—*A Practical Table of the Velocity of Engines with given Loads, and,* vice versa, *of the Load corresponding to a given Velocity.*

We have just given some examples of cases, in which it is wished to build an engine for a particular end. The contrary case naturally presents itself afterwards. The question is, what effect may be expected from a given engine, that is to say, from an engine already constructed, and the dimensions of which can be measured.

In order to give here a practical and extensive application of the formulæ which resolve this question, we shall calculate, after the formula, § 1, a table of the velocity which engines, similar to those of Liverpool, viz. with 11 and 12 in. cylinders, will acquire with given loads. By that means, the experiments, which we are going to make on the Liverpool engines, will serve to verify *by facts*, the accuracy of the formulæ, which we have deduced from principle.

As we think that this table, like the preceding ones, may be useful to practical men, in showing them the results, without obliging them to make the calculation, we shall extend it farther to engines of different powers, such as are most in use on railways.

It will be remarked, that this table, giving the velocity corresponding to known loads, naturally furnishes also the loads of the engine, when, on the contrary, the velocity is given *a priori*. In like manner, as we have necessarily been obliged to confine ourselves, in each column, to the limit of load which the engine is capable of drawing at the pressure indicated, after the formula in § 4; so it follows that the same table gives equally the maximum loads for each pressure, as well as their corresponding velocity.

In the last column, the state of the regulator is indicated as follows: when it is entirely open, we write 1; when only half open, ½ etc. This relates to the following tables, as well as to this one:

A PRACTICAL TABLE OF THE VELOCITY OF THE ENGINES WITH GIVEN LOADS, AND OF THE LOAD CORRESPONDING TO A GIVEN VELOCITY.

Description of the Engine.	Load in gross tons, tender includ.	Velocity on a level, in miles per hour, the effective pressure per square inch in the boiler being			State of the regulator.
		50 lbs.	55 lbs.	60 lbs.	
	tons.	miles.	miles.	miles.	
Engine with cylinders 11 in. or 0.917 ft.	25	40.07	40.38	40.60	1
Stroke of the piston 16 in. or 1.33 ft.	50	31.34	31.58	31.76	1
Wheel - - - - 5 ft.	75	25.74	25.93	26.06	1
Friction - - - - 110 lbs.	100	21.83	22.00	22.12	1
Area of heating-surface 140 sq. ft.	125	18.96	19.10	19.21	1
Or effective evaporating	150	16.75	16.88	16.97	1
power per hour - 42 cu. ft.	166	15.59	15.71	15.80	1
	175	—	15.12	15.21	1
	184	—	14.58	14.66	1
	202	—	—	13.67	1
Engine with cylinders 12 in. or 1 ft.	25	34.45	34.71	34.91	1
Stroke of the piston 16 in. or 1.33 ft.	50	27.80	28.01	28.16	1
Wheel . . . . 5 ft.	75	23.29	23.47	23.60	1
Friction . . . . 152 lbs.	100	20.05	20.21	20.32	1
Area of heating-surface 140 sq. ft.	125	17.60	17.73	17.83	1
Or effective evaporating	150	15.68	15.80	15.89	1
power per hour . 42 cu. ft.	175	14.14	14.25	14.33	1
	195	13.11	13.21	13.28	1
	200	—	12.98	13.05	1
	217	—	12.23	12.30	1
	255	—	—	10.91	1
Engine with cylinders 13 in. or 1.083 ft.	50	29.03	29.25	29.42	1
Stroke of the piston 16 in. or 1.33 ft.	75	24.68	24.86	25.00	1
Friction . . . 165 lbs.	100	21.46	21.62	21.74	1
Area of heating-surface 160 sq. ft.	125	18.98	19.13	19.23	1
Or effective evaporating	150	17.02	17.15	17.24	1
power per hour . 48 cu. ft.	175	15.42	12.54	15.63	1
	200	14.10	14.21	14.29	1
	225	12.99	13.09	13.16	1
	231	12.75	12.84	12.92	1
	256	—	11.92	11.99	1
	281	—	—	11.18	1
Engine with cylinders 14 in. or 1.166 ft.	50	29.83	30.06	30.22	1
Stroke of the piston 16 in. or 1.33 ft.	75	25.69	25.88	26.03	1
Friction . . . . 180 lbs.	100	22.56	22.73	22.86	1
Area of heating-surface 180 sq. ft.	125	20.11	20.26	20.37	1
Or effective evaporating	150	18.14	18.28	18.38	1
power per hour . 54 cu. ft.	175	16.52	16.64	16.74	1
	200	15.17	15.28	15.37	1
	225	14.02	14.12	14.20	1
	250	13.03	13.13	13.20	1
	269	12.37	12.46	11.53	1
	298	—	11.57	11.63	1
	327	—	—	10.85	1
Engine with cylinders 12 in. or 1 ft.	50	26.16	26.36	26.51	1
Stroke of the piston 18 in. or 1.50 ft.	75	22.57	22.74	22.87	1
Friction . . . . 165 lbs.	100	19.85	20.00	20.11	1
Area of heating-surface 160 sq. ft.	125	17.71	17.85	17.95	1
Or effective evaporating	150	15.99	16.11	16.20	1
power per hour . 48 cu. ft.	175	14.57	14.68	14.77	1
	200	13.39	13.49	13.56	1
	221	12.53	12.63	12.70	1
	246	—	11.73	11.80	1
	270	—	—	11.05	1

We remark here, as we have said above, that the whole influence of the pressure bears upon the limit of the load, but that its effect is almost insensible on the velocity. This result agrees with the principles; for if the pressure required on the piston to move the load, be, for instance, 46 lbs. per square inch, is it not true that, provided the steam be abundantly furnished at that pressure, by the heating surface, it is of little consequence whether it be at first collected in the boiler at a pressure of 75 lbs. or 65 lbs. or at any other degree? Finally, at the moment of acting, it must any how be transformed into steam at 46 lbs. pressure, and the speed will depend solely on the quantity of steam at 46 lbs. that the boiler will have furnished. The small advantage we observe here in favour of a greater pressure is only owing to the fire being in that case naturally more intense; a circumstance from which results, not that there is more water evaporated, but the same quantity, notwithstanding a higher pressure.

These tables show the effect that may be expected from an engine of giving proportions, in regard either to the speed or to the load; but it is understood that that effect can only be produced if the engine is put in a situation to apply all its power.

If, for instance, instead of the fire being sufficiently animated, it is left to languish, the quantity of water evaporated per minute will be diminished, and at the same time the effect of the engine.

If the engine, instead of being in good order, loses its steam, either by leaks in the boiler, or round the piston, or by the stuffing boxes, or elsewhere, it is clear that the effect must also be proportionately diminished.

If, by diminishing the opening of the regulator, we let only a portion of the generated steam penetrate into the cylinders, the boiler continuing at first to furnish the same quantity, more steam will necessarily be lost by the valves without acting on the pistons. Afterwards, as soon as the

diminution of the steam thrown into the chimney has moderated the fire, there will be less steam generated, and that will consequently regulate the velocity. This is the case of all small loads drawn by the engines. The speed is never suffered to augment sufficiently to risk an accident by too rapid a motion of the piston or other parts of the méchanism. When the enginemen perceive that the train would run too fast, they diminish the aperture of the regulator, and make a moderate fire, in order to maintain a reasonable speed. In all the experiments we shall have occasion to relate below, we shall only once see, as we have already observed, the speed rise to 35 miles an hour, which is the greatest speed to which the engines have been hitherto submitted, excepting for a very short instant.

In the above tables, the limits of load of the engines, with the indicated pressure, are fixed by the necessity of the resistance on the piston not being greater than the force that must move it, as we have already said. With that maximum load, we see that an eleven-inch cylinder engine, working at 60 lbs. effective pressure, will still maintain a velocity of 13½ miles; and a twelve-inch cylinder engine, with an effective pressure of 55 lbs., will still maintain a speed of 12 miles an hour. These velocities are those which will take place if the engine works in its right state; that is to say, if the valve is fixed for a pressure of 60 lbs. or 55 lbs. But if it should happen that the valve be only regulated for a pressure of 50 lbs., and the pressure of 60 lbs. or 55 lbs. be produced by an extraordinary rising of the valve and by dint of losing steam, that is to say, only because the steam above 50 lbs. cannot escape as quickly as it is generated, then it is clear that although the evaporating power of the boiler remains the same, the effective part of that power will be considerably reduced, and, consequently, also the velocity. It is for that reason that, in the experiments, we shall see the speed go sometimes down to two or three miles an hour. But the state of the valve must then be observed.

The elevated pressure will be seen to be produced only by an enormous loss of steam, and it will be easy, by the rising of the valve, to account for the diminution of speed.

In the cases of *maximum* load, it is evident that the steam will be spent by the cylinder, at the same pressure at which it has been generated in the boiler, and that the speed of the piston will be equal to the quickness with which the steam is generated. This fact has been proved in a general manner in § 5 of the present article. It may be verified here by calculating the velocity with which the quantity of steam, generated in a minute, would cross the cylinders without any alteration or reduction of pressure. The velocity of the engine resulting from it, will be found to coincide exactly with that indicated in the table. This is a proof that, in case the engine only advances at that speed, the pressure in the cylinder is equal to that in the boiler.

Those cases of limit loads are those of which we have made use to determine the friction of the loaded engine, and we see here the principle justified, of which we then made use, viz. that in case the speed of these engines is under 12 miles an hour, the pressure in the cylinder is the same as in the boiler.

We have one observation more to make, which is, that in the engines there always exists a small loss, which we have not taken into account in our calculation; that is to say, the loss of the steam which, at each stroke of the piston, fills the passages that lead from the slides to the cylinders. It would be easy to take it into account, by the measures taken on each engine, of the diameter and length of these passages; but this loss is very insignificant, and would only complicate the calculation without any advantage.

ARTICLE VII.

CONFIRMATION OF THE ABOVE FORMULÆ BY EXPERIMENTS.

SECTION 1.—*Experiments on the Velocity and Load of the Engines.*

As a verification of the formulæ we have laid down, and with a view to enable our readers to rest their calculations on material facts, we shall give here a series of experiments undertaken by us, in order to ascertain the speed with which the engines draw different loads, at different degrees of pressure of the steam, in their daily and regular work.

These experiments were made on the Liverpool and Manchester Railway, the section of which, according to a levelling made in the month of August 1833, by Mr. Dixon, resident engineer, is as follows. We only give the part travelled over by the locomotive engines; there are, besides, under the city of Liverpool, three tunnels worked by separate stationary steam engines.

The railway, on leaving the station at Liverpool, until it terminates at Manchester, passes over the following distances and slopes:

Miles.		
0.53	dead level.	
5.23	descent - - - -	at $\frac{1}{1094}$
1.47	ascent - - - -	at $\frac{1}{96}$
1.87	dead level.	
1.39	descent - - - -	at $\frac{1}{89}$
2.41	descent - - - -	at $\frac{1}{2762}$
6.60	descent - - - -	at $\frac{1}{845}$
5.62	ascent - - - -	at $\frac{1}{1300}$
4.36	ascent - - - -	at $\frac{1}{4237}$
29.48	miles.	

From these different inclinations, we see that the same train presents various degrees of resistance, according to the part of the road travelled over, because the gravity of the total mass in motion becomes an alleviation in the descents and an additional obstacle in the rising ground.

The result is, that a train of 100 t. offers on a dead level a resistance of 800 lbs., besides the friction of the engine; and that the same train, if it is, for instance, drawn by an engine weighing 10 t., will, on arriving at an ascent of $\frac{1}{96}$, offer a resistance of 3,366 lbs., which upon a dead level would be equal to the resistance of a train of 421 t.

In fact, if we observe that a ton weighs 2,240 lbs., we shall find for the resistance:

100×8 lbs. $=$ 800 lbs.; resistance owing to the friction.

$\frac{100 \times 2{,}240 \text{ lbs.}}{96} =$ 2,333 lbs. resistance owing to the gravity of the train, on a plane inclined at $\frac{1}{96}$.

$\frac{10 \times 2{,}240 \text{ lbs.}}{96} =$ 233 lbs. similar resistance owing to the gravity of the engine.

3,366 lbs. total resistance, (not including the friction of the engine,) equal to that of a load of $\frac{3366}{8} = 421$ t. on a level.

That is the manner in which we have calculated the real load of the engine on the different slopes it had to pass over during its journey.

The following column marks the pressure in the boiler, expressed first by the state of the balance, and then by its equivalent on the mercurial gauge. Thus, when the balance, fixed at 57, rose by the blowing to 58, we have written 57—58; and as for the Atlas, for instance, that state of the balance corresponds with an effective pressure by the mercurial gauge of 61 lbs., we have written 57—58=61 lbs.

We have also noted the state of the regulator: but we must add, that the handle of the regulator in these engines not turning on a graduated circle, as it would be better that it should, we have only been able to estimate the degree of opening of the regulator at sight and by approximation.

The speeds have been carefully taken down, by inscribing in minutes and quarters of minute the time when the engine passed before every quarter-mile stone of the road. These stones are numbered all along the way. At the same moment we noted the pressure in the boiler as marked on the valve balance.

The weight of the wagons was taken *exactly* in tons, cwts., quarters, and pounds. The tender cartwrights were not weighed, but they are reckoned at their average weight of 5½ t. when a fresh supply of water is taken in on the road and 5 t. only in the contrary case.

We have marked the state of the weather, because it is a known fact that with the wind a-head, and still more with a side-wind that presses the flange of the wheels against the rails, the resistance of the train is augmented. Finally, we have also mentioned the temperature of the water in the tender, in order that the reader may judge of the influence of that circumstance; and we have given the date of each of the experiments as a means of verification.

EXPERIMENTS ON THE VELOCITY AND LOAD OF THE ENGINES.

Date of the experiment and Designation of the engine and its load.	Inclination of the road.	Load of the engine reduced to a level.	Velocity in miles per hour.	Effective pressure in the boiler in pounds per square inch, by the state of the spring-balance	State of the regulator.	Remarks.
		tons.	miles.	lbs.		
1834.						
July 14, ATLAS, from Liverp. to Manchest.,	level . . .	124	17.14	57..58 = 61	$\frac{3}{4}$	The engine was helped on the inclined plane at 1·96 by three engines with cylinders 11 in. diameter Weather fair and calm.—Water cold in the tender.
in 1 h. 31′,...with 25 wagons . 118.90 t.	descent $\frac{1}{1094}$	90	21.17	57..... = 60	$\frac{3}{4}$	
delays 19′... tender . . 5.50	descent $\frac{1}{849}$	80	23.72	57..60 = 63	$\frac{3}{4}$	
——— ———	ascent $\frac{1}{1300}$	154	18.75	57..59.5 = 62.5	$\frac{3}{4}$	
1 h. 50′ 124.40 t.	ascent $\frac{1}{4257}$	133	17.89	57..58 = 61	$\frac{3}{4}$	
ATLAS { cylinder...12 in.						
stroke......16 in.						
wheel........5 ft. { 6 wheels, 4 coupled						
weight.....11.40 t.						
friction.... 152 lbs.						
heating surface ... { fire-box 57.06 sq. ft. tubes 217.88 sq. ft.						
July 16, ATLAS, from Liverp. to Manchest.,	level . . .	105	15.00	50..51 = 54	$\frac{3}{4}$	The engine was helped on the inclined plane at 1·96 by two engines with 11 inch cylinders.—Weather fair and calm.—Water rather lukewarm in the tender.
in 1 h. 25′,...with 20 wagons . 99.25 t.	descent $\frac{1}{1094}$	75	21.43	50..51 = 54	$\frac{3}{4}$	
delays 5′, tender 5.50	descent $\frac{1}{849}$	67	25.07	50..52 = 55	$\frac{3}{4}$	
——— ———	ascent $\frac{1}{1300}$	129	22.64	50..51.25 = 54.25	1	
1 h. 30′ 104.75 t.	ascent $\frac{1}{4257}$	112	19.63	50.. = 53	$\frac{3}{4}$	

EXPERIMEMTS ON THE VELOCITY AND LOAD OF THE ENGINES.

Date of the Experiment and Designation of the Engine and its load.	Inclination of the road.	Load of the engine reduced to a level.	Velocity in miles per hour.	Effective pressure in the boiler in pounds per square inch, by the state of the spring-balance.	State of the regulator.	Remarks.
1834.		tons.	miles.	lbs.		
July 17, ATLAS, from Liverp. to Manchest.,	level . . .	71	20.00	50... = 53	$\frac{1}{2}$	The engine was helped on the inclined plane at 1·96 by one engine with 11 inch cylinders.—The axle-box of one of the wagons too tight.—Weather fair and calm.—Water very hot in the tender.
in 1 h. 27′,...with 15 wagons . 65.4 t.	descent $\frac{1}{1094}$	50	24.54	50...51 = 54	$\frac{1}{2}$	
delays 3′, tender . . . 5.5	descent $\frac{1}{849}$	44	26.13	50... = 53	$\frac{1}{2}$	
	ascent $\frac{1}{1300}$	89	21.51	50...52 = 55	$\frac{1}{2}$	
1 h. 30′ 70.9 t.	ascent $\frac{1}{4257}$	76	20.81	50... = 53	$\frac{1}{2}$	
July 17, ATLAS, from Manchest. to Liverp.,						
in 1 h. 26′...with 8 empty wagons and	descent $\frac{1}{4257}$	26	26.47	50...51 = 54	$\frac{1}{3}$	The engine ascended, without help, the inclined plane at 1·89. On the remainder of the way, the engine drew two wagons more.—Weather fair and calm.—Water very hot in the tender.
3 loaded . . . 22.45 t.	descent $\frac{1}{1300}$	22	31.43	50...50.5 = 53.5	$\frac{1}{3}$	
delays 3′ tender . . . 5	ascent $\frac{1}{849}$	36	27.93	50...52 = 55	$\frac{1}{3}$	
	ascent $\frac{1}{89}$	114	15.00	50...53 = 56	1	
1 h. 29′ 27.45 t.						
July 23, ATLAS, from Liverp. to Manchest.,	level . . .	196	9.23	50...50.5 = 53.5	1	The engine was helped on the inclined plane at 1·96 by four engines, three with 11 in. cylinders, and one with 14 in. cylinders. Weather fair and calm.—Water cold in the tender.
in 3 h. 2′...with 40 wagons . 190	descent $\frac{1}{1094}$	142	14.12	50... = 53	1	
delays 15′ tender . . 5.5	descent $\frac{1}{849}$	127	16.21	50... = 53	1	
	ascent $\frac{1}{1300}$	240	8.00	50...51.75 = 55	1	
3 h. 17′ 195.5 t.	ascent $\frac{1}{4257}$	209	5.87	50...51.5 = 54.5	1	
July 23, ATLAS, from Manchest. to Liverp.,						
with 8 wagons . 33.90 t.	ascent $\frac{1}{89}$	199	6.00	50...52 = 55	1	Weather calm.
tender . . . . 5.50 t.						
39.40 t.						

EXPERIMENTS ON THE VELOCITY AND LOAD OF THE ENGINES.

Date of the Experiment and Designation of the Engine and its load.	Inclination of the road.	Load of the engine reduced to a level.	Velocity in miles per hour.	Effective pressure in the boiler in pounds per square inch, by the state of the spring-balance.	State of the regulator.	Remarks.
1834.		tons.	miles.	lbs.		
July 31, ATLAS, from Liverp. to Manchest.,	level . . .	67	20.00	30... =33.5	1	The engine ascended the inclined plane at 1.96 with its train in two trips.—Weather fair and calm.—In this experiment, the pressure was purposely varied. On the total delay, 26′ were employed in making an experiment.
in 1 h. 44′...with 14 wagons . 61.65 t.	descent $\frac{1}{1094}$	59	21.82	30... =33.5	1	
delays 52′ tender . . 5	descent $\frac{1}{849}$	53	23.26	30...30.33=34	1	
—— ——	ascent $\frac{1}{1300}$	96	19.75	25...27.75=31	1	
2 h 36′ 66.65 t.	ascent $\frac{1}{4257}$	84	14.16	20...21.5 =25.5	1	
July 31, ATLAS, from Manchest. to Liverp.,	level . . .	40	16.38	20...23 =27.25	1	The engine ascended the inclined plane at 1.89 without help.—Weather calm. In this experiment, as in the former one, the pressure was lowered on purpose.
in 1 h. 54′...with 8 wagons loaded and	descent $\frac{1}{4257}$	37	19.53	20...20.5 =25	1	
4 empty . . . 35.15 t.	descent $\frac{1}{1300}$	29	23.00	20...20.75=25.25	1	
delay ... tender . . 5	ascent $\frac{1}{849}$	57	16.08	20...20.75=25.25	1	
—— ——	ascent $\frac{1}{89}$	202	7.50	45...47.5 =51	1	
1 h. 54′ 40.15 t.	ascent $\frac{1}{1094}$	53	15.79	20...20.25=24.75	1	
Aug. 4, ATLAS, from Liverp. to Manchest.,	level . . .	128	15.00	50... =53	1	The engine was helped on the inclined plane at 1.96 by two engines, one with 11 in. cylinders, and the other with 14 in. cylinders. Weather fair and calm.—Water cold in the tender. We have seen in the experiments on the friction of the engines, that that day, ATLAS had a friction of 194 lbs. instead of 152 lbs.
in 1 h. 58′...with 25 wagons . 122.64 t.	descent $\frac{1}{1094}$	92	17.14	50... =53	1	
delay ... tender . . 5	descent $\frac{1}{849}$	82	20.52	50... =53	1	
—— ——	ascent $\frac{1}{1300}$	158	15.38	50...50.5 =53.5	1	
1 h. 58′ 127.64 t.	ascent $\frac{1}{4257}$	137	15.24	50... =53	1	

EXPERIMENTS ON THE VELOCITY AND LOAD OF THE ENGINES.

Date of the Experiment and Designation of the Engine and its load.	Inclination of the road.	Load of the engine reduced to a level.	Velocity in miles per hour.	Effective pressure in the boiler in pounds per square inch, by the state of the spring-balance.	State of the regulator.	Remarks.
1834.		tons.	miles.	lbs.		
Aug. 4, ATLAS, from Manchest. to Liverp., with 9 loaded wagons and						
7 empty . . . . 38.76 t.	ascent $\frac{1}{89}$	219	3.75	57...58.75=61.75	1	Weather fair and calm.
tender . . . 5.40						
44.16 t.						
July 24, FURY, from Liverp. to Manchester,	level . . .	56	17.14	31...32 = 55	$\frac{3}{4}$	The engine ascended the inclined plane without help.—Weather fair and calm.—Water cold in the tender.
in 1 h. 30'...with 10 wagons . 51.16 t.	descent $\frac{1}{1094}$	40	18.00	31...32 = 55	$\frac{3}{4}$	
delay ... tender . 5	ascent $\frac{1}{96}$	244	6.31	32...35 = 65.5	1	
	descent $\frac{1}{849}$	35	23.28	31...32 = 55	$\frac{3}{4}$	
1 h. 30' 56.16 t.	ascent $\frac{1}{1300}$	70	21.82	31...32.5 = 55.5	$\frac{3}{4}$	
	ascent $\frac{1}{4257}$	60	21.17	31...32 = 55	$\frac{3}{4}$	
FURY: cylinders . . 11 in.						
stroke . . 16 in.						
wheel . . 5 ft.						
weight . 8.20 t.						
friction . 109 lbs.						
heating surface: firebox 32.87 sq. ft.; tubes 307.38 sq. ft.						

EXPERIMENTS ON THE VELOCITY AND LOAD OF THE ENGINES.

Date of the experiment and Designation of the engine and its load.		Inclination of the road.	Load of the engine reduced to a level.	Velocity in miles per hour.	Effective pressure in the boiler in pounds per square inch, by the state of the spring-balance.	State of the regulator.	Remarks.
			tons.	miles.	lbs.		
1834.							
July 24, FURY, from Manchest. to Liverp.		level	49	17.50	31..32 = 55	$\frac{3}{4}$	The engine ascended the inclined plane without help.——Weather fair, a side-wind blowing tolerably hard at intervals.—Water cold in the tender.
in 1 h. 35′...with 10 wagons .	43.80 t.	descent $\frac{1}{4237}$	45	21.43	31..32 = 55	$\frac{3}{4}$	
delay .... tender . .	5	descent $\frac{1}{1300}$	36	22.00	31..32 = 55	$\frac{3}{4}$	
		ascent $\frac{1}{849}$	68	18.62	31..32 = 55	$\frac{3}{4}$	
1 h. 35′	48.80 t.	ascent $\frac{1}{89}$	228	15.00	32..36 = 67	1	
		ascent $\frac{1}{1097}$	63	18.46	31..32 = 55	$\frac{3}{4}$	
Aug. 4, FURY, from Manchest. to Liverp.		level	38	25.00	28..30 = 52.5	1	The engine went up the inclined plane without help.—Weather fair and calm.
in 1 h. 15′ with 8 first class coaches	32.97 t.	descent $\frac{1}{4237}$	35	25.71	28..31 = 54	1	
delays 9′ tender . .	5	descent $\frac{1}{1300}$	28	26.94	28..30.25 = 53	1	
		ascent $\frac{1}{849}$	53	24.61	28..30 = 52.4	1	
1 h. 24′	37.97 t.	ascent $\frac{1}{89}$	183	13.33	28..33 = 55	1	
		ascent $\frac{1}{1094}$	50	4.82	28..30 = 52.5	1	
Aug. 15, FURY, from Manchest. to Liverp.		level	138	10.91	31..32.5 = 55.5	1	The engine only travelled that part of the road with this train. Its fire was in its greatest activity only towards the end of the journey. It had, besides, the impulse proceeding from the descent of the plane at 1.96.—Weather fair.—Rails muddy.
with 28 wagons . .	132.73 t.	ascent $\frac{1}{1094}$	176	13.33	31..32.5 = 55.5	1	
tender . .	5.50						
	138.23 t.						

EXPERIMENTS ON THE VELOCITY AND LOAD OF THE ENGINES.

Date of the experiment and Designation of the engine and its load.	Inclination of the road.	Load of the engine reduced to a level.	Velocity in miles per hour.	Effective pressure in the boiler in pounds per square inch, by the state of the spring-balance.	State of the regulator.	Remarks.
1834.		tons.	miles.	lbs.		
July 26, Firefly, from Liverp. to Manchest.	level	41	24.00	17.... = 50	1	The engine was in bad order, and was going to be repaired. It was helped on the inclined plane at 1·96 by another engine with 11 inch cylinders.—Weather fair.—Water almost cold in the tender.
in 1 h. 35′ with 8 first class coaches 36.40 t.	descent $\frac{1}{849}$	25	25.45	15.... = 45	1	
delays 5′ tender . . . 5	ascent $\frac{1}{1300}$	52	21.29	15.... = 45	1	
1 h. 40′ 41.40.t	ascent $\frac{1}{4237}$	45	21.33	11.... = 35	1	
Firefly: cylinders . 11 in.; stroke . . 18 in.; wheel . . 5 ft.; weight . . 8.74 t.; friction . 119 lbs.; heating-surface: firebox 43.91 sq. ft., tubes 362.60 sq. ft.						
July 26, Firefly, from Manchest. to Liverp.	level	41	25.71	17..18 = 50.33	$\frac{1}{2}$	The engine was in bad order. It was helped on the inclined plane at 1·89 by an engine with 11 in. cylinders.—Weather rainy—Wind tolerably strong against the direction of the engine.
in 1 h. 18′ with 8 first class coaches 36.40 t.	descent $\frac{1}{4237}$	38	23.68	15..... = 45	$\frac{1}{2}$	
delay 5′ tender . . 5	descent $\frac{1}{1300}$	31	24.44	17..18 = 50.33	$\frac{1}{2}$	
	ascent $\frac{1}{849}$	58	23.44	17.18.5 = 50.5	$\frac{1}{2}$	
1 h. 23′ 41.40 t.	ascent $\frac{1}{1094}$	54	24.82	17..... = 50	$\frac{1}{2}$	

EXPERIMEMTS ON THE VELOCITY AND LOAD OF THE ENGINES.

Date of the Experiment and Designation of the Engine and its load.	Inclination of the road.	Load of the engine reduced to a level.	Velocity in miles per hour.	Effective pressure in the boiler in pounds per square inch, by the state of the spring-balance.	State of the regulator.	Remarks.
1834.		tons.	miles.	lbs.		
Aug. 1, Vesta, from Liverp. to Manchest.	level . . .	49	24.00	20..21.5 = 52	1	The engine ascended, without help, the inclined plane at 1·96, until about 60 yds. from the top. It was hauled up the remainder of the ascent.—Weather calm.—Water warm in the tender. The delay of 30 minutes on the road was occasioned by an experiment made on engine.
in 1 h. 22′...with 10 wagons . 43.72 t.	descent $\frac{1}{1094}$	34	29.09	20..21 = 50	1	
delays 30′ tender . . 5	descent $\frac{1}{849}$	30	27.00	20..21 = 50	1	
——— ———	ascent $\frac{1}{1300}$	61	23.56	20..21.5 = 52	1	
1 h. 52′ 48.72 t.	ascent $\frac{1}{4257}$	52	25.71	20..21 = 50	1	
Vesta: cylinders 11⅛ in.						
stroke . 16 in.						
wheel . 5 ft.						
weight . 8.71 t.						
friction . 1.87 lbs.						
heating surface: fire-box 46.00 sq. ft.; tubes 256.08 sq. ft.						
Aug. 1, Vesta, from Manchest. to Liverp.	level . . .	33	29.00	20..21 = 50	1	The engine ascended the inclined plane at 1·96 without help.—Weather fair.—Wind moderate, in favour of the motion.—Water very hot in the tender.
in 1 h. 5½′...with 5 loaded wagons and 5	descent $\frac{1}{4257}$	30	30.00	20..21 = 50	1	
empty . . . 28.15 t.	descent $\frac{1}{1300}$	24	34.74	20..21 = 50	1	
delay ... tender 5	ascent $\frac{1}{849}$	47	28.93	20..21 = 50	1	
——— ———	ascent $\frac{1}{89}$	165	14.11	20..22.5 = 55	1	
1 h. 5½′ 33.15 t.	ascent $\frac{1}{1094}$	44	28.80	20..21 = 50	1	

EXPERIMENTS ON THE VELOCITY AND LOAD OF THE ENGINES.

Date of the experiment and Designation of the engine and its load.	Inclination of the road.	Load of the engine reduced to a level.	Velocity in miles per hour.	Effective pressure in the boiler in pounds per square inch, by the state of the spring-balance.	State of the regulator.	Remarks.
1834.		tons.	miles.	lbs.		
Aug. 16, VESTA, from Manchest. to Liverp.	level . . .	94	15.00	20..21.5 = 52	1	The engine drew a part of its train on the inclined plane at 1-89. The remainder was drawn by an additional engine.—Weather fair and calm.—Water lukewarm in the tender. The delays that occurred in the journey were occasioned by several trials made with the engine.
in 1 h. 42′...with 20 wagons . 88.35 t.	descent $\frac{1}{4257}$	87	18.46	20..22 = 53.25	1	
delays 1 h. 10′ tender . . . 5.50	descent $\frac{1}{1300}$	71	24.00	20..22 = 53.25	1	
——— ———	ascent $\frac{1}{849}$	129	12.10	20..22.5 = 55	1	
2 h. 52′ 93.85 t.	ascent $\frac{1}{1094}$	121	18.75	20..21.5 = 52	1	
Aug. 16, VESTA, from Manchest. to Liverp. with 8 wagons . 31.95 t. tender . 5.50 ——— 37.45 t.	ascent $\frac{1}{89}$	183	3.25	20..23.5 = 58	1	Weather calm.——Water lukewarm in the tender.——These eight wagons were part of the train of the former experiment.
Aug. 16, VESTA, from Manchest. to Liverp. with 8 loaded wagons and 4 empty . . . 34.05 t. tender . . 5.00 ——— 39.05 t.	ascent $\frac{1}{89}$	189	3.00	20..23 = 56.5	1	Weather fair and calm.

EXPERIMENTS ON THE VELOCITY AND LOAD OF THE ENGINES.

Date of the Experiment and Designation of the Engine and its load.	Inclination of the road.	Load of the engine reduced to a level.	Velocity in miles per hour.	Effective pressure in the boiler in pounds per square inch, by the state of the spring-balance.	State of the regulator.	Remarks.
1834.		tons.	miles.	lbs.		
Aug. 15, LEEDS, from Liverp. to Manchest.	level . . .	88	18.26	31...32.75=54.75	$\frac{3}{4}$	The engine was helped for the passage of the inclined plane at 1·96 by an engine with 14 inch cylinders.—Weather calm.—Water rather less than lukewarm in the tender. The regulator was not quite opened, because the engine is subject to *prime*, that is to say, to drive the water of the boiler into the cylinder with the steam.
in 1 h. 35'...with 20 wagons . 83.34 t.	descent $\frac{1}{1094}$	64	20.72	31...32 =54	$\frac{3}{4}$	
delay ... tender . . 5	descent $\frac{1}{849}$	57	24.00	31...32 =54	$\frac{3}{4}$	
——— ———	ascent $\frac{1}{1300}$	109	20.34	31...32 =54	$\frac{3}{4}$	
1 h 35' 88.34 t.	ascent $\frac{1}{4257}$	95	18.82	31...32 =54	$\frac{3}{4}$	
LEEDS { cylinder - 11 in.; stroke - - 16 in.; wheel - - 5 ft.; weight - - 7.07 t.; friction - 108 lbs.; heating-surface { fire-box 34.57 sq. ft.; tubes 307.38 sq. ft. } }						
Aug. 15, LEEDS, from Manchest. to Liverp.	descent $\frac{1}{4257}$	37	24.54	28...30 =51.5	$\frac{3}{4}$	The engine ascended, without help, the inclined plane at 1·89.—Weather fair and calm.—Water very hot in the tender.
in 1 h. 17½', delay 3' { 1st half of the way { 8 wagons 34.38 t.	descent $\frac{1}{1300}$	30	30.00	25...27 =46.5	$\frac{3}{4}$	
tender - 5.50	ascent $\frac{1}{849}$	55	25.31	25...27 =46.5	$\frac{3}{4}$	
——— 39.88 t. }						
——— 1 h. 20½' { 2d half of the way { 7 wagons 29.65	level . . .	35	22.50	25...27 =46.5	$\frac{3}{4}$	
tender - 5.50	ascent $\frac{1}{89}$	168	10.00	28...29 =48.5	1	
——— 35.15 t. } }	ascent $\frac{1}{1094}$	46	25.71	28...32 =54	$\frac{3}{4}$	

EXPERIMENTS ON THE VELOCITY AND LOAD OF THE ENGINES.

Date of the Experiment and Designation of the Engine and its load.		Inclination of the road.	Load of the engine reduced to a level.	Velocity in miles per hour.	Effective pressure in the boiler in pounds per square inch, by the state of the spring-balance.		State of the regulator.	Remarks.
1834.			tons.	miles.		lbs.		
Aug. 15, LEEDS, from Liverp. to Manchest.		level . . .	38	21.81	25...28	=47.5	$\frac{3}{4}$	The engine while ascending, without help, the inclined plane at 1-96 with its load, stopped near the top. It was hauled up the remainder of the ascent.—Weather fair and calm.—Water lukewarm in the tender. The delay that occurred on the road was occasioned by a trial made with the engine.
in 1 h. 29'...with 7 wagons .	33.52 t.	descent $\frac{1}{1094}$	27	29.09	31...32	=54	$\frac{3}{4}$	
delay 36' tender .	5	descent $\frac{1}{849}$	23	28.96	25...28	=47.5	$\frac{3}{4}$	
———	———	ascent $\frac{1}{1300}$	48	21.43	15...16	=29	$\frac{3}{4}$	
2 h. 5'	38.52 t.	ascent $\frac{1}{4257}$	41	18.75	25...27	=46.5	$\frac{3}{4}$	
July 22, VULCAN, from Manchest. to Liverp.								
with 9 first class coaches .	34.07 t.							
tender . . .	5							
	———	ascent $\frac{1}{89}$	188	11.42	31...36	=57.5	1	Weather calm.—Water scarcely lukewarm in the tender on leaving Manchester.
VULCAN { cylinders . 11 in.	39.07 t.							
stroke . . 16 in.								
wheel . . 5 ft.								
weight . 8.34 t.								
friction . 136 lbs.								
heating surface { firebox 34.45 sq. ft.								
tubes 307.38 sq. ft. }								
July 22, VULCAN, from Liverp. to Manchest.								
with 9 first class coaches .	36.32 t.							
tender . .	5	ascent $\frac{1}{96}$	186	18.75	31...36	=57.5	1	Weather fair.—A very slight wind against the motion of the engine.—Water cold in the tender.
	———							
	41.32 t.							

These experiments show better than any possible reasonings, what may be expected of locomotive engines in a daily work. That is the reason why we have joined them all together in this place.

Their coincidence with the table of velocities, deduced from calculation, will be remarked.

SECTION 2.—*Of the Velocity of the Maximum useful Effect.*

We have seen above (Chap. V. Art. V. § 2) that the load an engine is able to draw, at a given speed, is expressed by

$$M = \frac{m\,SPD - \rho\, d^2 l V}{(\delta + n)\, V D} - \frac{F}{\delta + n}.$$

If we multiply the two members of this equation by V, we have

$$M\,V = \frac{m\,S\,P\,D - \rho\, d^2 l V}{(\delta + n)\, D} - \frac{F\,V}{\delta + n}.$$

The produce M V, of the load multiplied by the velocity with which that load is drawn, represents the *useful effect* produced by the engine in unit of time. We see consequently, here, that that useful effect will be so much the greater as the speed is less; for in the second member that speed only appears in the negative terms. As, on the other hand, the engine cannot, without considerable loss of steam, move at a velocity less than that which corresponds to the quickness with which the steam is generated in the boiler, it follows that the *maximum* of useful effect will take place at that speed.

By examining the above table, under the same point of view, we ascertain by experience what has already been proved by calculation, viz., that the greatest useful effect is produced at the least velocity.

Let us take, for instance, an engine with an eleven-inch cylinder, working 10 hours a day. At its greatest speed, of 30 miles an hour, it will be able, with an effective pres-

sure of 50 lbs. per square inch in the boiler, to draw 50 t.; and at its least speed, with an equal pressure in the boiler, it will draw 160 t.

By drawing trains of 50 t. at a velocity of 30 miles an hour, it will, in its 10 hours' work, have drawn 50 t. to a distance of 300 miles, or, in other words,

15,000 t. to the distance of one mile.

By drawing trains of 160 t. at a speed of 15.5 miles an hour, it will, in the same space of time, have taken 160 t. to a distance of 155 miles, which is equal to

24,800 t. to the distance of one mile.

There is, consequently, a considerable advantage to be reaped, in making the engine, if possible, work with the greatest loads, which correspond with the least speeds. It must be remarked, that the difference between the two effects would have been still greater, if from each load we had deducted the tender, as making, in regard to their useful effect, a part of the engine, and not of the train.

It is scarcely necessary to add, that when the speed becomes the express condition of the haulage, as, for instance, in respect to passengers, these considerations are no longer applicable. We speak here only theoretically.

The difference we have found in the useful effect produced, is owing to the circumstance that in the two cases the resistance proper to the engine remained nearly the same, while in the first case it had to be moved 300 miles, and in the second only 155 miles. The same is true in regard to the atmospheric pressure, which forms a part of the resistance on the piston. The engine having travelled in one circumstance double the distance of the other, was naturally obliged to give a double number of strokes of the piston; and as at each of these strokes of the piston the atmospheric pressure must be overcome, we see that the expense of moving power necessary to conquer the resistance of the atmosphere is in the proportion of the numbers 300 and 155; that is to say, that that force, as well as the force required to

move the engine, is in proportion to the velocity of the motion. This is a farther proof that, in calculating the effect of these engines, one cannot, as is usually the case, neglect, in all circumstances, the atmospheric pressure; and that it is only in those cases in which the speed is not taken into account that that simplification can take place without mistake.

If we sometimes find calculations of the power of locomotive engines, or any other sort of steam-engines, in which there appears what is termed *lost power*; that is to say, calculations according to which it would appear that these engines produce in practice only one-third or even a quarter of what is termed their *theoretical power;* and if that difference between practice and theory be at present so generally established, that it is taken as a rule to say that *practical horses* are only the third part of *theoretical horses*, the reason is, simply, that this supposed theoretical power is wrongly calculated. All the different circumstances of which we have spoken above have not been duly taken into account. Before all calculations, the atmospheric pressure has been deducted; the resistance of the engine, or its increase in proportion to the load, has been omitted; and, above all, the pressure on the piston has been calculated as equal to the pressure in the boiler, though we have seen how different they are from each other. With so many causes of error, it is not surprising that results should have been obtained, which are contradicted by experience; or, in other words, that one should construct very good engines without being able to calculate their power or effects. But if we take into account all the resistances really conquered, and the velocity of their points of application; if we take the pressure in the cylinder as it really is, instead of considering a power as applied when it is not; in that case we shall obtain a most remarkable result, applicable, moreover, to all sorts of steam-engines, viz. that all the power applied is to be traced in the effect produced, and that there is not one single pound of which the use may not be pointed out.

CHAPTER VI.

OF SOME ACCESSORY DISPOSITIONS AND THEIR EFFECT.

ARTICLE I.

OF THE REGULATOR.

SECTION 1.—*Effect of the opening of the Regulator.*

Three accessory parts or dispositions are still to be considered, which have a considerable influence on the effect of locomotive engines; these are the *regulator*, the *blast-pipe*, and the *lead* of the slide, which we are going to describe successively.

We have observed that the pipe, which leads from the boiler to the cylinders, may be either completely or partially shut by means of a cock or regulator. When the regulator is quite open, the steam enters into the cylinder as freely as the area of the pipe through which it must necessarily pass will allow. Then the speed is as great as the generation of steam permits. If, by means of the regulator, we diminish a little the entrance of the pipe, the steam may take at first a greater velocity, which surplus of velocity may allow, as before, the egress of all the steam generated. In that case the effect will remain the same as in the former one, and as long

as the width of the passage is not out of proportion with the generation of the steam, there will be no diminution in the effect of the engine.

If, however, we continue to shut the passage, we shall necessarily arrive at last at a point where it will be so narrow, that it will form a considerable obstacle to the admission of the steam. From that moment, only a portion of the steam generated in the boiler will be able to get into the cylinders, and consequently the effect produced will be diminished in the same proportion.

Having called *effective* evaporating power the mass of steam the engine is able to introduce into the cylinders in a unit of time, we clearly see that the motion imparted to the regulator causes a diminution in the effective evaporating power of the engine; and then the formula, such as we have given it above, shows why the effect is diminished.

In fact, we find in practice that the same train will be drawn by the same engine at different speeds according to the size of the aperture of the regulator. This is the method invariably used on the Liverpool Railway to prevent the trains, when they are too light, from being carried along with greater rapidity than the preservation of the engines, the carriages, and the railway can allow. This manner of regulating the speed is so far advantageous, that, if on the road there occur either a slight inclination or any obstacle whatever, one may, by opening the regulator, and animating at the same time the fire, restore to the engine its full power, and enable it to pass over the obstacle without diminishing its speed.

The size of the aperture of the regulator is, therefore, to be taken into account, when the question is to ascertain the effect of an engine. That is the reason why we have noted it in the experiments related above. We should have preferred the handle of the regulator to have turned on a graduated circle, in order to be able to measure exactly the degree of opening, and compare it with the corresponding effects;

but, with the present construction of the engines, it is only by approximation that we can judge of the size of the aperture.

Section 2.—*Of the Steam Pipes.*

Carrying still farther the same principle, on the free motion of the steam, we see that between two engines, perfectly similar in other respects, there must be an advantage in favour of that one in which the steam-pipes have a more considerable area. It is, however, clear, that as soon as we have attained a diameter sufficient for the passage of all the steam that a boiler is able to generate, at the greatest speed with which the engine is required to go, nothing farther is to be gained by augmenting still more that diameter. It is for the same reason that we have seen, a little while ago, that that passage may be reduced to a certain degree without loss of effect, which is owing to the opening having been originally greater than was necessary.

Experience has fixed the diameter that must be given to the steam pipes, and would quickly give notice if it were not observed; for if it should happen, for instance, that an engine, running with all its speed, should still emit steam through its safety-valve, that would be a proof that the area of the passage is too small for the quantity of steam the boiler is able to generate.

Section 3.—*Table of the Dimensions of the Steam-Pipe in some of the Engines of the Liverpool and Manchester Railway.*

There exists, then, a suitable diameter, harmonizing with the evaporating power of the engine, or with the dimensions of the boiler. It is for that reason we give here the diameter of the steam-pipes, in the engines we have submitted to experiment, and in some others, the proportions of which

were given at the beginning of this work. The steam-pipes considered here are those which lead separately from the boiler to each slide-box. Those which lead afterwards from that box to the interior of the cylinders have a corresponding area, although of a different form. Their dimensions will be, for instance, 1 inch broad to 7 inches long, which present the same surface, as a tube of 3 inches diameter.

DIAMETER OF THE STEAM-PIPES IN SOME OF THE ENGINES OF THE LIVERPOOL AND MANCHESTER RAILWAY.

Name of the engine, and number of its construction.	Diameter of the cylinder.	Stroke of the piston.	Heating surface. Exposed to the action of radiating caloric.	Heating surface. Exposed to the action of communicative heat.	Inside diameter of the steam-pipes.	Remarks.
	inches.	inches.	sq. ft.	sq. ft.	inches.	
SAMSON, No. 13	14	16	40.20	416.90	3.25	This engine is now under repair, and the steam-pipes will be 4 in. diameter.
GOLIATH, No. 15	14	16	40.31	407.00	3.25	
ATLAS, No. 23	12	16	57.06	217.88	3.25	
VULCAN, No. 19	11	16	34.45	307.38	3.50	
FURY, No. 21	11	16	32.87	307.38	3.50	
VESTA, No. 24	11⅛	16	46.00	256.08	3.25	
LEEDS, No. 30	11	16	34.57	307.38	3.50	
FIREFLY, No. 31	11	18	43.91	362.60	3.00	

ARTICLE II.

OF THE BLAST-PIPE.

In describing the engine, we have said that the steam, after having produced its effect in the cylinder, is let into the chimney. It enters in a jet, through a pipe turned upwards, and terminated by a narrow orifice, which is placed in the

middle of the chimney-flue. The disposition of that pipe, called the *blast-pipe*, is represented in fig. 5.

The steam, at each jet, clearing before it the column of air that filled the passage of the chimney, leaves a vacuum behind it. This vacuum is immediately filled up with a mass of exterior air that rushes through the fire-place to occupy the space where the vacuum has been made. In consequence, after each aspiration thus produced, the fuel in the fire-place grows white with the intensity of the heat.

This effect is similar to that of a pair of bellows that would constantly animate the fire, and the artificial blast created by that means in the fire-place is so necessary to the work of the engine, that if the pipe happens to be broken, burnt, or leaky, the engine becomes almost useless; which shows that the ordinary draft of the chimney is very small in comparison.

It is easy to conceive, that the narrower the orifice, the more violent will be the current that escapes through it, and the greater its effect in animating the fire. The result is, consequently, a greater generation of steam in the same space of time, or an increase of power in the engine. This is, therefore, an important point to note when the effect produced by an engine is to be described; for if the diameter of the blast-pipe is changed the evaporating power of the boiler will be changed also.

In the engines that served for the above experiments, the diameter of the orifice of the blast-pipe was $2\frac{1}{4}$ to $2\frac{1}{2}$ in., which is their usual dimension. The Leeds engine must, however, be expected from the general rule, the diameter of her blast-pipe being only $2\frac{3}{16}$ in. As for the Atlas engine, her blast-pipe was $2\frac{15}{16}$ in. in diameter in all the experiments, except on the 4th of August, when it had been carried to $3\frac{1}{16}$ in., in order to observe what reduction would result from that circumstance on the effect of the engine. Comparing that experiment with the others made with the same engine, the diminution of speed seems to

have been nearly in the proportion of 15 to 17. The effect produced would thus be in the inverse proportion of the square of the diameter of the pipe, or of the area of the orifice; that is to say, in a direct ratio to the velocity with which the steam escapes into the chimney.

To those dimensions, therefore, as to one of the elements of production, must be referred the evaporation effected by the engines.

The generally adopted dimension of $2\frac{1}{4}$ to $2\frac{1}{2}$ in. diameter for the orifice of the blast-pipe is the result of experience. It has been endeavoured to diminish the aperture as much as possible, without putting a material obstacle to the escaping of the steam; that is to say, that the tube has been narrowed as long as the effect was seen to augment, and that a stop was put to the trial as soon as it was found that there was no more gain of power.

With an orifice $2\frac{1}{2}$ in. in diameter, or 5 sq. in. area, and cylinders of 11 in. diameter, or 190 sq. in. total area; that is to say, with an orifice which is only $\frac{1}{38}$ of the area of the cylinders, we see, that in order that all the steam may get out by that passage, its speed in passing through the orifice must be 38 times as great as it was in the cylinder.

The velocity of the jet formed in the chimney will then be, for the dimension we consider, equal to 38 times the velocity of the piston, or in other words, equal to $6\frac{1}{2}$ times the speed of the engine, this latter speed being nearly six times as great as that of the piston.

Thus the power of this additional means will be greater in proportion as the velocity of the engine itself will be more considerable. If, for instance, the engine travels 30 miles an hour, the velocity of the jet will be 195 miles an hour, or 286 feet per second; and as that velocity cannot be produced merely by the tendency of the steam to escape into the atmosphere, a part of the power of the engine itself must necessarily, in those great speeds, be spent in expulsing the steam; that is to say, in blowing the fire in the fire-place.

Consequently, the increase of effect being produced by a sacrifice of power, a point will naturally come where the profit is balanced by the expense required to obtain it, and there all advantage will cease. This explains the point determined by practice as the limit of the narrowing of the orifice.

ARTICLE III.

OF THE LEAD OF THE SLIDE.

Section. 1.—*Nature and Effects of the Lead.*

The third disposition which we have to discuss, is the *lead* of the slide.

In describing the different parts of the engine, we said that it is the slide that opens and shuts successively the passages above and below the piston, so as to apply the effort of the steam alternately on one side and on the other. If the engine were regulated, as it appears natural that it should be, the slide would keep the passage open to the steam until the piston had reached the bottom of the cylinder. At that instant the change would take place. The first passage would be shut, and the opposite passage opened. Then the motion of the slide would accompany exactly that of the piston. Their alternation would be strictly simultaneous.

But this is not the case; it has been found by experience, that the engine is capable of acquiring a greater speed when the motion of the slide precedes a little that of the piston; that is to say, when it opens the passages to the steam a little before the necessary moment. When the engine is regulated in that manner, at the moment the piston is going to begin a new stroke, the passages, instead of beginning to

open, have already a certain degree of aperture. This premature degree of aperture is called the *lead of the slide*, because it indicates in how far the motion of the slide precedes that of the piston. In fact, we can conceive, that if the return of the slide is, for instance, a quarter of an inch in advance on that of the piston, the passages for the steam will have a quarter of an inch aperture when the piston touches the bottom of the cylinder.

The effect of that disposition, first on the speed and then on the load, are the two points we intend to examine here.

The common way of explaining the increase of speed the engine acquires when it has a little lead, is by saying, that by that means the steam is ready to act on the piston at the moment the piston begins its stroke. But it is not difficult to see, that if the steam really acts quicker at the beginning of the stroke, it is also sooner interrupted at the end of the stroke. The effect would thus only be, to add on one side what is substracted on the other. That explanation is, therefore, by no means satisfactory.

But the manner in which the calculation of the speed of the engines has been established hereabove, gives us immediately the real explanation of the fact.

If the change in the passages of the steam, instead of occurring exactly at the end of the stroke of the piston, takes place according to our supposition, at the moment the piston is still an inch from the bottom, from that instant no more steam enters the cylinder. In fact, on one side the passage is shut; it is true that it is open on the other, but the piston, which must necessarily finish its stroke, keeps the steam pressed back in the passages, from whence it cannot get out until the piston begins to take its retrogade direction. Thus, in regard to the quantity of steam admitted in the cylinders at each stroke of the piston, the length of that stroke is in reality diminished by an inch. We have seen that, to know the velocity of the piston, we must divide the mass of steam generated in the boiler by the area of the cylinders (Chap. V. Art. V. § 1), and that the quotient will be the speed with

which that volume of steam must necessarily pass through the cylinders, or the velocity of the piston. That will really give the velocity wanted, if the steam issues without any interruption; but if, as it is here the case, there occurs at each stroke a suspension in the issuing of the steam, it is evident that, for the same quantity of steam to go through the cylinders, a greater velocity of motion will be required. It is the generation of steam in the boiler that regulates and limits the speed; if, therefore, we suppose that the generation supplied m cylinders full of steam in a minute, when the total length l of the cylinder got filled with steam, now that the length $l - \varsigma$ only gets filled, the same quantity of steam will fill per minute a number of cylinders expressed by $m \times \frac{l}{l - \varsigma}$. Then the speed of the piston will be augmented in the inverse proportion of the length of cylinders that get full of steam.

We see why the lead is favourable to the speed. But if there be profit in that respect, there is loss in regard to the load that the engine is able to draw.

Suppose the line E D (fig. 25) represents the stroke of the piston, and that the stroke takes place in the direction of the arrow. The passage being shut on one side of the piston a little before it is opened on the other side, as we shall see below, let A be the point where the piston is, when the arrival of the steam is intercepted on the side E, and let C be the point where it is when the slide begins to admit the steam on the opposite side, that is to say, on the side D.

It is clear, that at the instant the piston reaches the point A, the moving power that produced the motion is suppressed. Moreover, when the piston, continuing its stroke by virtue of its acquired velocity, reaches the point C, not only has it ceased receiving any impulsion in the direction of the motion, but it suffers even an opposition from the steam admitted in a contrary direction. The piston, however, cannot stop. It must finish its stroke. It must, therefore, re-

pulse that fresh steam that opposes it. As it necessarily spends in the conflict a force equal to that which the steam would have communicated to it, the consequence is, that during the space C D there is not only suspension of the action of the moving force, but even introduction of that moving force in a contrary direction, and in the same proportion destruction of the force previously acquired.

We see, therefore, that the effect of the moving power, in regard to the motion, is only produced on the length of the stroke, first diminished of A D, and then of C D; so that, if those two distances are represented by β and α, the effect we are really entitled to expect from the engine is only in proportion of a stroke $l - \beta - \alpha$.

Now we have seen (Chap. V. Art. V. § 4) that the limit of load an engine can draw, is determined by calculating the pressure on the piston as equal to the pressure in the boiler, or expressed by—

$$M = \frac{(P - p)\, d^2\, l}{(\delta + n)\, D} - \frac{F}{\delta + n},$$

expression in which l represents the stroke of the piston. It is then clear, that the limit of load will be smaller in proportion as the stroke is diminished, and that, setting aside the friction of the engine, or the term $\frac{F}{\delta + n}$, the load will be reduced in proportion to the length of the stroke.

Thus we see what are the effects of the *lead*.

The *maximum* load the engine is able to draw becomes less considerable, and its diminution is very nearly in the proportion of $\frac{l - \alpha - \beta}{l}$.

On the other hand, for all loads that remain below that limit, the engine increases its speed in the proportion of $\frac{l}{l - \beta}$.

The surplus of effect produced in the latter case is by no means surprising. It is the natural effect of the diminution

of the stroke, which enables the same mass of steam generated in the boiler to supply a greater number of cylinders in one case than in the other; and the general formula of the velocity for a given load shows it at first sight. That formula is (Chap. V. Art. V. § 1.)

$$V = \frac{m \, P \, S \, D}{(F + \delta M + n \; M) \, D + \rho \, d^2 \, l}.$$

The quantity l, which represents the stroke of the piston, only enters in the denominator. Thus, the shorter the stroke, the greater will be the velocity of the motion with the same load.

A similar effect may, besides, have been already observed in the engines. We mean the effect which results from the difference in the diameter of the cylinder. Between two engines, the cylinders of which have 12 and 11 inches diameter, all things being equal besides, the first will be able to draw a more considerable load; but with equal loads inferior to those limits, the 11-inch engine will have the greatest speed. These results are shown by the above-stated formula, and can be explained in the same manner as the effects of the lead.

Section 2.—*Calculation of the effects of the lead.*

This is sufficient when we only wish to explain the causes of observed effects. But if we want to calculate *a priori*, and know exactly the effects of a given lead, it is necessary to ascertain the precise measure of the distances α and β. That is to say, that we must determine the situation of the piston corresponding with that of the slide, at the moment that it intercepts or opens the passages.

To be able to determine the comparative situations of the slide and the piston, four circumstances already explained in the description of the engine (§ 6, 7, 8,) and which form the connexion of motion between those two parts of the

mechanism, must be clearly kept in mind. (See fig. 9 and 10.)

The slide moves backwards and forwards on the three apertures of the cylinder. It goes alternately from one of its extreme positions to the other without stopping.

This motion is produced by the revolution of the radius of the eccentric round the axis of the axle-tree, which makes the effect of a common crank. But as the communication between the eccentric and the slide takes place by means of a cross head, the slide is pushed forward when the eccentric is behind, and *vice versa.*

The radius of the eccentric stands at right angles with the crank; the consequence is, that when the crank is horizontal, the eccentric is, on the contrary, vertical, and consequently the slide is in its middle position. *Vice versa,* when the crank is vertical, the eccentric is horizontal, and the slide in its extreme position.

Finally, the piston is exactly at the end of its stroke when the crank is horizontal. Thus, it results from the preceding article that the middle position of the slide corresponds with the end of the stroke of the piston. These different effects are represented in fig. 9 and 10.

From these coincidences we see that, when the slide is in its middle position (fig. 10,) the eccentric is vertical, the crank horizontal, and the piston at the end of its stroke.

When the slide is in one of its extreme positions (fig. 9) the eccentric is horizontal, the crank vertical, and the piston in the middle of the cylinder.

We see, moreover, that if the slide had no lead at all, that is to say, if the eccentric were to stand rigorously at right angles with the crank, the middle position of the slide would correspond exactly with the end of the stroke of the piston. If it deviates a little from the perpendicular, that is to say, if the slide reaches its middle position a little before the piston gets to the bottom of the cylinder, the difference will exactly be the lead we are considering.

This being granted, let us take the slide when it is in its middle position, and consequently, when the eccentric is exactly in the vertical. At that moment all is shut, as we see represented in fig. 10 and 26. But the dimensions of the slide being such that on all the openings there exists a small lap, which is generally of $\frac{1}{8}$ of an inch, we see that the passages were already shut an instant before this, viz., $\frac{1}{8}$ of an inch before the slide had reached this position. Thus, the direction of its motion being marked by the arrow, when the slide was in the position *a* (fig. 26) all the passages began to be shut, and the steam was consequently intercepted. This is then the point at which the action of the lead begins, or which corresponds with the point A of the stroke of the piston in fig. 25.

While the slide passes from the position *a* to the position *b*, and afterwards to the position *c*, every thing remains in the same state; but once arrived at the point *c*, the passage on the right side begins to open and to admit the steam on the opposite side of the piston. This is then the point corresponding with the one we have designated by C in the motion of the piston.

After having passed that point *c*, the slide continues to open more and more a passage to the steam. If the lead is $\frac{5}{8}$ of an inch, for instance; that is to say, if the slide opens the passage to an extent of $\frac{5}{8}$ of an inch, at the instant the piston finishes its stroke, then, in measuring from the point *c* a distance of $\frac{5}{8}$ of an inch, we shall find the point *d* where the slide will be the moment the piston is at the bottom of the cylinder. This point will consequently correspond with the one designated by D in fig. 25; that is to say, it will correspond with the end of the stroke of the piston.

This correlativeness once established, we have to determine the unknown distances AD and CD, taken on the stroke of the piston, according to the distances *ac cd*, taken on the range of the slide. These last are in fact given, the

second being the lead, and the first the same lead augmented by twice the lap *ab*.

Now, if we suppose the motion of the slide backwards and forwards to be 3 in., the eccentric must produce that motion, and consequently the interval between its centre and the centre of the axle must be $1\frac{1}{2}$ in. The centre of the eccentric describes consequently round the axle a circle, the diameter of which is 3 in., while the crank of the axle describes a circle, the diameter of which is 16 in., which we suppose to be the length of the stroke.

If, therefore, we take the point *b* (fig. 27) for the centre of the axis, and if round that point we describe a circle, the radius of which be $1\frac{1}{2}$ in., that circle will be the one described by the eccentric; and its diameter will be the space run over by the slide. If round that point we describe another circle with a radius of 8 in., it will be the circle described by the crank; and its diameter will be the stroke of the piston.

These points acknowledged, since the middle situation of the slide corresponds with the moment the eccentric is vertical, we see that that position of the slide is here the point *b*. As, besides, we have seen that in consequence of the slide lapping over the apertures, the steam is intercepted an instant before, if we take before the point *b* a space equal to the lap, we shall have the point *a* where the effect of the lead begins. In the same way, if we take beyond the point *b* another space, also equal to the lap, we shall have the point *c* where the passages open again. And, finally, at a distance from the point *c* equal to the lead, we shall have the point *d*, which corresponds with the end of the stroke of the piston.

Raising from these points perpendicular lines towards the circumference described by the eccentric, the points a', b', c', d', will be those described by the eccentric, while the slide takes the positions indicated by *a*, *b*, *c*, *d*.

But while the eccentric describes the arc $a'\,d'$, the crank of the axletree describes necessarily an equal angle. As that

crank must be horizontal or coincide with bD at the end of the stroke of the piston, if from the point p we trace arcs equal to $d' c'$, $d' b'$ and $d' a'$, or in other words, arcs, the sines of which be, dc, db and da; and if we draw radii through the points thus determined, we shall evidently have in A′, B′, C′ and D′, the points where the crank was, while the eccentric passed through the points a', b', c' and d'. Letting perpendiculars fall from the points A′, B′, C′, D′, on bD, we shall at last have in A, B, C, D, the corresponding situations which we sought for the piston.

Thus we recapitulate: while the slide passes from the point a, where it begins to intercept the steam, to the point c, where it opens the opposite passage, and to the point d, end of the lead; the eccentric will run through the points a', c', d'; the crank, on its circle, will run through the points A′ C′ D′; and, finally, the piston will be successively at the point A, where it ceases to receive the impulse of the steam, at the point C, where it meets it opposing its motion, and at the point D, where it finishes its stroke.

Now, it will not be difficult to express by precise measures the spaces CD and AD, which we have represented above by α and β.

For that purpose, it will be sufficient in practice to trace exactly, and by the scale, the fig. 27, and then to measure the resulting spaces CD, AD.

To obtain those same quantities by calculation, we have

$$AD = bD - bD \cos A'bD,$$

And, at the same time, expressing the arc $A'bD$ by γ,

$$\operatorname{Sin} \gamma = \frac{ms}{bp} = \frac{ad}{bp}.$$

But bD is the half stroke of the piston, which we have expressed by l; and bp is the half range of the slide, which we shall express by l'. If, besides, we call a the lead of the slide or cd, and let r represent the lap of the slide over the apertures or ab, ad will be expressed by $a + 2r$. Thus the quantity sought AD or β will be

$$\beta = \frac{l}{2} - \frac{l}{2}\cos\gamma,$$

The value of γ being given by the additional equation,

$$\operatorname{Sin}\gamma = \frac{a + 2r}{\frac{1}{2}l'} = \frac{2a + 4r}{l'}.$$

In the same manner, we shall have for CD, or α:

$$\alpha = \frac{l}{2} - \frac{l}{2}\cos\gamma',$$

And γ' will be known by the equation:

$$\operatorname{Sin}\gamma' = \frac{2a}{l'}.$$

The quantities α and β, of which we have made use in the preceding paragraph, will, consequently, be determined by the stroke of the piston, the range of the slide, the lead, and the lap, all of which are known quantities. Thus we will be enabled to calculate immediately the effect of the lead, either on the speed or on the load.

Having seen that the speed of the engine will be increased in the proportion of $\frac{l}{l - \beta}$, the consequence will be, for the augmentation of the speed a ratio of

$$\frac{l}{l - \beta} = \frac{l}{\frac{l}{2} + \frac{l}{2}\cos\gamma} = \frac{2}{1 + \cos\gamma}.$$

In the same manner, the limit of the load of the engine will be reduced as if the length of stroke of the piston was no more than $l - \alpha - \beta$, or

$$l - \alpha - \beta = \frac{}{2}(\cos\gamma + \cos\gamma';)$$

And in these two values, the arcs γ and γ' will be given by the above equations, viz.

$$\operatorname{Sin}\gamma = \frac{2\,a + 4\,r}{l}, \text{ and } \operatorname{Sin}\gamma' = \frac{2\,a}{l'}$$

The use of trigonometrical signs might be avoided in these formulæ; but it would make them less convenient for calculation.

In order to apply them, let us take, for example, an engine with a 16 in. stroke, range of the slide 3 in., lap of the slide over the apertures $\frac{1}{8}$ in., and let us suppose a lead of $\frac{5}{8}$ in. given to the engine.

In that case, $\frac{2\,a + 4\,r}{l} = \frac{7}{12} = 0.58333$. The arc, the sine of which is $\frac{2\,a + 4\,r}{l}$, is consequently the arc, the sine of which is 0.58333; or, taking the logarithms, it is the arc, the logarithm sine of which is 9.76591.

Seeking that arc in the tables, we find that the logarithm of its cosine is 9.90967; and finishing the calculation, we find

$$\mathfrak{C} = 8 \text{ in.} - 8 \text{ in.} \times 0.81222 = 1.50 \text{ in.}$$

In the same manner,

$$\alpha = 8 \text{ in.} - 8 \text{ in.} \times 0.90906 = 0.73 \text{ in.}$$

Thus we see that, in this case, the piston is at a distance of $1\frac{1}{2}$ in. from the bottom of the cylinder, at the moment the action of the moving power is taken away from it; and it is at $\frac{3}{4}$ in. when that same power is introduced against it. Fig. 27 constructed by the scale gives the same results.

From what has been said above, the speed will be augmented in the proportion of $\frac{l}{l - \mathfrak{C}}$ or $\frac{16}{14.5}$, for all the loads that do not pass the limit of power of the engine thus regulated.

And the limit of that load will be reduced, as if the stroke, from the length that it had, be reduced to the length, $l - \alpha - \mathfrak{C} = 13.77$ in.

We find also, by supposing for the engine a lead of $\frac{1}{8}$ in., that the space that the piston has still to travel, when the steam is intercepted, is 0.25 in.; and that the steam is introduced in a contrary direction, when the piston is still within 0.03 in. from the bottom of the cylinder. From thence results that, with the above lead, the speed is augmented in the proportion of $\frac{16}{15.75}$, and that the *maximum* load is diminished as if the length of the stroke was reduced to 15.72 in.

Let us take, for an example, an engine like **Vesta**, viz.

d, diameter of the cylinder $11\frac{1}{8}$ in., or 0.927 ft.

1, stroke of the piston 16 in., or 1.33 ft.

D, diameter of the wheel 60 in., or 5 ft.

F, friction of the engine 187 lbs.

The limit of the load being given by the formula (Chap. V. Art. V. § 4,)

$$M = \frac{(P - \rho)\, d^2 l}{(\delta + n)\, D} - \frac{F}{\delta + n},$$

We see that if the engine work at the effective pressure of 56.5 lbs. per square inch, as we shall have an example of it in a moment, the limit of load will be

In case of no lead at all - - -	187 t.
In case of a lead of $\frac{1}{8}$ in. - - -	183 t.
In case of a lead of $\frac{5}{8}$ in. - -	158 t.

In these same circumstances, according to the formula (Chap. V. Art. V. § 1,) the velocity of the engine will be as follows:—

The load of 187 t. will be drawn at a velocity of 13.81 miles an hour.

The load of 183 t., which, if there had been no lead, would have had a speed of 14.03 miles, will have an augmentation of speed in the proportion of $\frac{16}{15.75}$, that is to say, that the speed will be 14.25 miles an hour.

Finally, the speed of the load of 158 t, which, with no lead, would have been 15.54 miles, will, in consequence of the lead, become 17.14 miles per hour.

We see by these results, that the effect of the lead, either in regard to the speed or to the *maximum* load, are only very perceptible when the lead is rather considerable.

Section 3.—*Experiments on the Effects of the Lead.*

The foregoing calculation gives us the loss of power produced in the engine in consequence of the lead.

However, no research having as yet been made on the

subject, every thing is at present regulated by opinion alone. There are some engine builders that give no lead at all; others only $\frac{1}{16}$, or $\frac{1}{8}$ in. at most; others, on the contrary, give $\frac{5}{8}$ in. or more. Although the lead, if moderately used, undoubtedly facilitates the working of the engine, it is also evident, that if carried too far, it must at last stop its effect. For that reason, we resolved to undertake some experiments on the subject.

In our research, we first made use of the Leeds engine, and we made the three experiments of the 15th of August, related above (Chap. V. Art. VII. § 1:) the first, with a lead of $\frac{3}{8}$ in.; the second, with no lead; and the third, with a lead of $\frac{1}{8}$ in. But as in the change in the load, in the pressure, and in the inclination of the road, caused naturally much complication in the results, we soon gave up that engine, and took in its place the Vesta. An ingenious apparatus, invented by Mr. J. Gray, of Liverpool, and fixed to this engine, made it easy to change the lead without interrupting the journey; so that, with the same load, and on the same spot, the engine could be tried successively, with different leads. The effect was produced by means of three notches, placed more or less backwards on the eccentric, and on which the driver might be brought at will by means of the common catching lever. The first of these notches gave a lead of $\frac{1}{8}$ in., the second of $\frac{3}{8}$ in., and the last corresponded with a lead of $\frac{5}{8}$ in. To make the difference more remarkable, we endeavoured to obtain a comparison between the first and third of these positions of the slide.

The reader will recollect that the Vesta engine has the following proportions:—

Cylinders - - - -	$11\frac{1}{8}$ in.
Stroke of the piston - - -	16 in.
Wheel - - - - -	5 ft.

1. On the 16th of August, 1834, in the morning, arriving with the engine and a train of 20 wagons at the foot of the inclined plane of Whiston, the inclination of which is $\frac{1}{89}$, all

the train was taken off except the first seven wagons, weighing together 34.43 t., and with the tender, 39.93 t.; and the engine endeavoured to ascend the plane with that load.

The lead was first regulated at $\frac{3}{8}$ in. Arrived at the foot of the plane with an acquired velocity of 10 miles an hour, the engine continued its motion for some time, but slackened visibly; and, after having travelled $\frac{3}{4}$ mile, it stopped; the pressure being at $23\frac{1}{2}$ lbs. by the balance.

The lead was reduced to $\frac{1}{8}$ in. The engine set off again, and reached the top of the plane with a velocity of 14 complete strokes of the piston per minute, the pressure by the balance being reduced to $23\frac{1}{4}$ lbs.

II. In the evening of the same day, the engine having taken to the same place a train of eight loaded wagons, and 12 empty ones, the eight wagons alone were left attached, their aggregate weight being 27.05 t., and with the tender, 32.05 t. With that load it began the ascent of the plane with an acquired speed of 10 miles an hour.

Lead, $\frac{3}{8}$ in. The engine arrived at the top without stopping. Pressure at the balance, 23 lbs. Velocity, 46 complete strokes of the piston per minute.

III. The engine having returned to the bottom with the same eight wagons, six empty ones were attached behind them, making with the loaded wagons a total weight of 43.18 t., and tender included, 48.18 t.

This load was too much for the engine, even with its smallest lead. Pressure, 23 lbs. Two of the empty wagons were taken off.

IV. The engine then drew a train of eight loaded wagons and four empty ones, making together a weight of 34.05 t., and tender included, 39.05 t.

A lead of $\frac{3}{8}$ in. was given; the engine was unable to start on the plane.

The lead was reduced to $\frac{1}{8}$ in.; the engine started, and augmented gradually its velocity, giving successively 11

strokes of the piston per minute; then 11 again, then 14, and then 17.

The lead was once more tried at $\frac{5}{8}$ in.; the engine stopped again.

The lead of $\frac{1}{8}$ in. was resumed; the train started again. Pressure during the whole experiment, 23 lbs. by the balance.

V. The train continuing to ascend, two more empty wagons were taken off; there remained then, in all, eight loaded and two empty ones, weighing together 30.38 t., and with the tender, 35.38 t.

Lead $\frac{5}{8}$ in. The engine stops; pressure 23 lbs. by the balance.

Lead, $\frac{1}{8}$ in. It starts again; same pressure.

VI. At last one more empty wagon is taken off, and the weight of the train is reduced to 28.55 t., and tender included, to 33.55 t.

Lead $\frac{5}{8}$ in. The engine stops; pressure, 23 lbs. by the balance.

Lead $\frac{1}{8}$ in. It starts again, and reaches the top, although, in consequence of the length of the experiment, the pressure diminishes by degrees from 23 to $21\frac{1}{2}$ lbs. by the balance.

The engine executed thus, at $21\frac{1}{2}$ lbs. pressure, what, with a lead of $\frac{5}{8}$ in., it could not execute with a pressure of 23 lbs.

This series of experiments gives us very nearly the exact measure of the power of the engine in both cases, or the loss of power resulting from the difference in the lead.

Section 4.—*Table of the Results obtained in these Experiments.*

In order to place these experiments together before the eyes of the reader, we unite them in the following table:—

EXPERIMENTS ON THE EFFECTS OF THE LEAD.

Name and designation of the engine.	Number of the experiment.	Load of the engine, tender included.	Lead $\frac{5}{8}$ inch. State of the motion.	Lead $\frac{5}{8}$ inch. Effective pressure in pounds per square inch, by the balance.	Lead $\frac{1}{8}$ inch. State of the motion.	Lead $\frac{1}{8}$ inch. Effective pressure in pounds per square inch, by the balance.
		tons.		lbs.		lbs.
VESTA, cylinders $11\frac{1}{4}$ in.	III	48.18	stopped	20..23 = 56.5	stopped	20..23 = 56.5
stroke 16 in.	I	39.93	stopped	20..23.5 = 58	star.agn.	20..23 25 = 57.25
wheel 5 ft.	IV	39.05	stopped	20..23 = 56.5	star.agn.	20..23 = 56.5
weight 8.71 t.	V	35.38	stopped	20..23 = 56.5	star.agn.	20..23 = 56.5
friction 187 lbs.	VI	33 55	stopped	20..23 = 56.5	star.agn.	20..21.5 = 52
	II	32.05	continued its motion.	20..23 = 56.5		

According to those experiments, all that an engine can do with a lead of $\frac{5}{8}$ in., is to draw a load weighing, without the tender, 27.05 t.

And with a lead of $\frac{1}{8}$ in., it will be able to draw a load weighing, without the tender, 34.05 t.

Thus, comparing the *useful effects* of the engine in the two cases, we see that they are in the proportion of 4 to 5, which constitutes in practice a considerable advantage in favour of the smallest lead.

In order, however, to obtain an *absolute* measure of the power an engine is able to display in the two circumstances, we must calculate the total resistance that was opposed to the motion of the piston in each case.

In the first, the engine drew a load, tender included, of 32.05 t. on an inclination of $\frac{1}{89}$. On account of the gravity of the mass on the plane, including 8.71 t. for the weight of the engine, the train was equal, on a level, to a load of 160 t.

In the second case, the engine drew on the same inclination a train of 39.05 t., equal to a load of 189 t. on a level.

We see that these numbers agree very nearly with those deduced from calculation. If those given by the experiment seem to be a little larger, the reason is, because we

reckon the tender at an invariable weight of five tons,—whereas, during this long experiment, the consumption of water and coke must have made it descend considerably below that weight, though we had no possibility of weighing the tender, and consequently we could not take the difference into account. We have said, that when the tender is quite empty, its weight is no more than three tons, which upon a level is two tons less than we reckon here, and makes, on the inclined plane at $\frac{1}{18}$, a reduction of eight tons in the load.

We may consequently conclude from experience, as well as from theory, that *the decrease of power occasioned by the lead is in proportion to the resulting decrease in the useful length of the stroke of the piston.*

Section 5.—*A Practical Table of the Effects of the Lead.*

In order to facilitate practical researches, we shall calculate here, according to the formulæ laid down above, § 2, a table of the effects of the lead, for different engines of the most usual proportions on railways.

By these formulæ, the velocity of the motion with no lead at all being known, that which will result from a certain lead represented by a, will be to the first in the ratio of

$$\frac{2}{1 + \cos \gamma};$$

but, at the same time, the *maximum* load of the engine will be reduced as if the stroke of the piston were reduced to the length

$$\frac{l}{2}(\cos \gamma + \cos \gamma';)$$

The arcs γ and γ' being determined by the equations,

$$\text{Sin } \gamma = \frac{2\,a + 4\,r}{l'}, \text{ and Sin } \gamma' = \frac{2\,a}{l'}.$$

The reader will recollect that in these formulæ the signs have the following significations:

l, length of the stroke of the piston expressed in feet.

a, lead of the slide.

l', length of the range of the slide.

r, lap of the slide over the apertures of the cylinder.

These three last quantities may be indifferently expressed in feet or in inches, the equations containing only their ratio.

Applying, then, these formulæ to a series of different cases, we form the following table, which will show, at a glance, how the velocity increases when the lead is augmented. As, on the other hand, in the second column, we could not go beyond the load the engine is capable of drawing with its supposed lead, the same table also shows what diminution in the maximum load corresponds to that increase in velocity. It is with a view to make the comparison between these two effects more conspicuous, that we have extended the table farther than the importance of the subject seems otherwise to require.

A PRACTICAL TABLE OF THE EFFECTS OF THE LEAD.

Designation of the Engine.		Load in gross tons, tender includ.	Velocity in miles per hour, the lead being			
			0.	1/8 in.	1/4 in.	3/8 in.
		tons.	miles.	miles.	miles.	miles.
Engine with cylinders 11 in. or	0.917 ft.	50	31.02	31.52	32.51	34.23
Stroke 16 in. or - -	1.33 ft.	100	21.68	22.02	22.72	23.92
Wheel - - - -	5 ft.	141	17.39	17.66	18.22	19.18
Friction - - - -	120 lbs.	155	16.28	16.54	17.06	0.
Heating-surface - -	140 s. ft.	163	15.72	15.96	0.	0.
Effective pressure in boiler	50 lbs.	165	15.58	0.	0.	0.
Range of the slide -	3 in.					
Lap over the apertures	1/8 in.					
Engine with cylinders 12 in. or	1 ft.	50	27.80	28.24	29.13	30.68
Stroke 16 in. or - -	1.33 ft.	100	20.05	20.37	21.01	22.12
Wheel - - - -	5 ft.	150	15.68	15.93	16.43	17.30
Friction - - - -	150 lbs.	168	14.56	14.79	15.25	16.06
Heating-surface - -	140 s. ft.	183	13.72	13.94	14.38	0.
Effective pressure in boiler	50 lbs.	193	13.22	13.43	0.	0.
Range of the slide -	3 in.	196	13.11	0.	0.	0.
Lap over the apertures	1/8 in.					
Engine with cylinders 13 in. or	1.083 ft.	50	29.03	29.49	30.42	32.03
Stroke 16 in. or - -	1.33 ft.	100	21.46	21.80	22.48	23.68
Wheel - - - -	5 ft.	150	17.02	17.29	17.83	18.78
Friction - - - -	165 lbs.	197	14.25	14.47	14.93	15.72
Heating-surface - -	160 s. ft.	216	13.37	13.58	14.01	0.
Effective pressure in boiler	50 lbs.	227	12.91	13.11	0.	0.
Range of the slide -	3 in.	231	12.75	0.	0.	0.
Lap over the apertures	1/8 in.					
Engine with cylinders 14 in. or	1.166 ft.	50	29.83	30.30	31.26	32.91
Stroke 16 in. or - -	1.33 ft.	100	22.56	22.92	23.64	24.89
Wheel - - - -	5 ft.	150	18.14	18.43	19.00	20.01
Friction - - - -	180 lbs.	200	15.17	15.41	15.89	16.73
Heating-surface - -	180 s. ft.	229	13.85	14.07	14.51	15.28
Effective pressure in boiler	50 lbs.	252	12.96	13.16	13.58	0.
Range of the slide -	3 in.	265	12.50	12.70	0.	0.
Lap over the apertures	1/8 in.	269	12.37	0.	0.	0.
Engine with cylinders 12 in. or	1 ft.	50	26.16	26.57	27.41	28.86
Stroke 18 in. or - -	1.50 ft.	100	19.85	20.16	20.80	21.90
Wheel - - - -	5 ft.	150	15.99	16.24	16.75	17.64
Friction - - - -	165 lbs.	188	13.93	14.15	14.60	15.37
Heating-surface - -	160 s. ft.	207	13.09	13.30	13.72	0.
Effective pressure in boiler	50 lbs.	217	12.69	12.89	0.	0.
Range of the slide -	3 in.	221	12.53	0.	0.	0.
Lap over the apertures	1/8 in.					

From these results we see that too great a lead detracts a considerable portion from the power of the engine. It is therefore necessary not to exceed, in that respect, certain limits.

It is, besides, easy to know the lead, or to regulate it at any degree.

After having opened the chamber situated under the chimney, and taken off the top of the slide-box, in order to see the slides work, the engine must be pushed gently forward on the rails, until the crank of the axle be perfectly horizontal.

Then the piston is at the bottom of the cylinder. If at that moment the passages which the slide opens to the steam be measured, it will give exactly the lead.

If we wish to alter the lead, we keep the crank in the same position, and loosening the driver which is fastened to the axle only with a screw, we turn the eccentric, until the slide, which moves at the same time, opens the passage as much as is wanted. Then we replace the driver so as to fix the eccentric in that position. This operation concluded, it is clear that whenever the crank is horizontal, or the piston ready to begin its stroke, the slide will open the passage to the degree required.

There are some ways of altering the lead without opening each time the chimney chamber; but they are not quite exact, and some of them are injurious to the engine.

In the experiments we have related above on the velocity and load of the engines, the *Vesta* engine was the only one in which the lead was considerable enough to have a remarkable effect on the speed.

CHAPTER VII.

OF THE CURVES AND INCLINED PLANES.

ARTICLE I.

OF THE CURVES.

Section I.—*Of the conical form of the Wheels and surplus of elevation of the Rails, calculated to annul the effect of the Curves.*

We have considered the dispositions proper to the engine, that may either favour or impede its effect. We have still to examine two external circumstances that may have a similar influence on the motions.

The curves offer on the railways an additional resistance which is so much the greater according as the degree of their incurvation is more considerable.

The wagons being of a square form, tend to continue their motion in a straight line. If, therefore, they are obliged to follow a curve, the flange of the wheel does no longer pass in a tangent along the rail without touching it, as it does in a direct motion. The rail, on the contrary, presents itself partially crosswise before the wheel, and opposes thus its

progress, by forcing it to deviate constantly from its direction.

Moreover, the wheel that follows the exterior rail of the curve has naturally more way to travel, than that which follows the interior rail. Now, in the wagons at present in use, the two wheels of the same pair are not independent of one another. They are fixed on the axletree that turns with them. If therefore the road travelled by one of the two wheels be less than that of the other, the latter one must necessarily be dragged along without turning on the difference of the two roads.

Finally, on passing the curves, the wagons are thrown by the centrifugal force of the motion against the outward rail, the result of which is a lateral friction of the flange of the wheel against the rail, which does not exist in the direct motion.

It is possible to construct the wheels of the wagons and the railway itself in such a manner, that these three additional causes of resistance may be destroyed. The mode we are going to describe, in order to obtain that effect, is that which is already known; viz., the conicalness of the tire of the wheel, and a greater elevation of the outward rail at the place of the curve. But those means have until now been employed only by approximation, and fulfil more or less imperfectly the intended purpose. By submitting them to calculation, we trust we shall be able to deduce general rules, which will make us certain that the required effect will be obtained.

The particular resistance, owing to the passage of the curves, is composed of two distinct parts, as to their causes and their effects.

The first, according to what we have seen above, is occasioned by the wagons being obliged to turn along the curve, which produces an opposition of the rail to the motion, and a dragging of the wheel.

The second is owing to the centrifugal force, and pro-

duces the friction of the flange of the wheel against the rail.

The first of these two resistances will evidently be corrected, if we succeed in constructing the wheels of the wagon in such a manner that the wagon may follow of itself the curve of the railway. For that, it will be sufficient to make the wheel slightly conical, with its greatest diameter inside; that is to say, towards the body of the wagon, as appears on the engine in fig. 2.

By that disposition, when the centrifugal force throws the wagon on the outside of the curve, the wheel on that same side will then rest on a tire of a larger diameter. Two effects will result from this. The wagon will no longer tend to follow a straight line. One of its wheels growing larger than the other, will, on the contrary, have a tendency to turn in the direction of the curve. Besides which, the two coupled wheels will naturally travel different lengths of road without any dragging on the rail.

This form of the wheel and its effect being well understood, we have first to determine what difference of diameter must be created between the two wheels, in order that the wagon may turn of itself with the curve, and how much the wagon must deviate on one side in order to produce that difference of diameter. Then we shall see how the railway must be constructed, in order that the centrifugal force of the motion produce of itself that lateral deviation. It will thus be clear, that those different conditions being fulfilled, the first species of resistance of the curve will be destroyed by the motion itself. Coming to the friction of the flange of the wheel against the rail, we shall determine what degree of conicalness the wheel must have, in order that, even in passing over the most abrupt curve of the railway, the lateral deviation of the wagon may never go so far as to put the flange in contact with the side of the rail. In this way, both by the disposition of the rails and by the form of the wheels, the two species of resistance will be destroyed.

Let us suppose that mm' and nn' (fig. 28) be the two lines of rails of the way. In order that the wagon may follow without effort the curve of the way, it is necessary that, while the outsidewheel describes the arc mm', the inside wheel describes of itself the arc nn', which terminates at the same radius as the first. If, therefore, the length mm' represent a circumference of the outside wheel, nn' must also be a circumference of the inside wheel, and the diameters of the two wheels must be in a certain proportion for that effect to be produced.

Let D be the diameter of the first wheel, and D′ that of the second, π being the ratio of the circumference to the diameter, we shall have—

$$mm' = \pi D, \text{ and } nn' = \pi D'.$$

Now the two arcs being both terminated by the same radius, we have—

$$\frac{mm'}{nn'} = \frac{mo}{no}.$$

If we express the radius of curvation os by r, and the half breadth of the road by e, this proportion may be expressed thus:—

$$\frac{mm'}{nn'} = \frac{r + e}{r - e};$$

then,

$$\frac{D}{D'} = \frac{r + e}{r - e};$$

and, finally,

$$D - D' = D\left(1 - \frac{r - e}{r + e}\right) = \frac{2\,e\,D}{r + e}.$$

This equation shows the differences that must exist between the diameters of the wheels, that the required effect may be obtained.

Our intention being to produce that effect, by pushing the wagon aside on the road, the question is, how much the wagon must be laterally displaced.

This point depends evidently on the degree of conicalness of the wheel.

At Liverpool, the wheels of the wagons have 3 ft. diameter at the interior part or near the flange, and 2 ft. 11 in. at the exterior part. The wheel is originally cylindrical, but the conical form is produced by the addition of a second tire, the breadth of which, not including the flange, is $\frac{1}{2}$ in. less on one side than on the other. Fig. 29, represents the section of that tire on a scale of $\frac{1}{4}$. Its breadth being $3\frac{1}{2}$ in., we see that its conical inclination is $\frac{1}{2}$ in. on $3\frac{1}{2}$ in., or $\frac{1}{7}$.

Let us suppose in general the inclination of the tire expressed by $\frac{1}{a}$. The two wheels running originally upon equal tires, in order that the difference $D - D'$ be produced in their diameters, by the displacing of the tire on the rail, this lateral displacing of the wheel must evidently be

$$\tfrac{1}{4}\, a\, (D - D';)$$

for the inclination of the tire being $\frac{1}{a}$, this displacing will produce on the thickness of the tire, or on the radius of the wheel, a difference of

$$\tfrac{1}{4}\, (D - D',)$$

which will make on the diameter

$$\tfrac{1}{2}\, (D - D'.)$$

This difference on the diameter will be produced in plus on the outside wheel, and as an equal difference, but in a contrary sense, that is to say, in minus, will be produced on the inside wheel; the result will be a total difference of $D - D'$ between the actual diameter of the two wheels, as we have said.

Thus the lateral motion to be produced is

$$\tfrac{1}{4}\, a\, (D - D') = \frac{aeD}{2(r+e)}.$$

We know at present what must be the lateral displacing of the wagon, in order to destroy the first species of resistance. The question now is, to make use of the centrifugal

force to produce that effect. It is its natural tendency; but it is evident that that force must produce exactly the necessary displacing, else the defect would by no means be corrected.

If we represent by r the radius of curvation, by V the velocity of the motion, and by m the mass of the body moved, the centrifugal force produced on the curve will be, as is known, expressed by

$$f = m\frac{V^2}{r}.$$

But P being the weight of that same body, and g the accelerating force of gravitation, we have

$$P = gm, \text{ from whence } m = \frac{P}{g};$$

thus

$$f = \frac{P}{g}\frac{V^2}{r},$$

which is the expression of the centrifugal force of a body of a given weight P, moving with a velocity V, on a curve the radius of curvation of which is r.

In this expression, g is the accelerating force of gravitation, or the double of the space passed over in the unit of time by a body falling in a vacuum. Taking a second for the unit of time, and a foot for the unit of space, we have $g = 32$. Referring to the same units the velocity V, and the radius of curvation r, we shall have the measure of the centrifugal force expressed by its proportion to the weight P, or represented by a weight.

Let us suppose, for instance, that the velocity of the motion be 20 miles an hour, or 29. 3 ft. per second, and the radius of the curve 500 ft.; we shall have

$$f = P \times \frac{\overline{29.3}^2}{32 \times 500} = \tfrac{1}{19} P.$$

So in that case the centrifugal force will be the nineteenth part of the weight of the body in motion.

The sense of the signs being now well understood, we return to the general expression of the centrifugal force

$$f = P \times \frac{V^2}{gr}$$

The effort of this force exerting itself in the direction of the radius, its effect will be to push all the wagons out of the curve. If the two sides of the railway are of equal elevation, the wagons will be stopped in the lateral motion only by the friction of the flange of the wheel against the rail. But if we give to the outward rail a surplus of elevation, above the inward one, it is clear that, in increasing sufficiently that elevation, we shall be able to master at last the centrifugal force, in such a manner as to permit it only to produce just the displacing we want. In fact, by raising in that manner the outward side, we change the railway in an inclined plane. The wagons placed on that plane ought, by virtue of their gravity, to slip towards the lower rail. On the other hand, the centrifugal force pushes them against the outward rail, which is the highest. We create, then, by that means, a counterpoise to the centrifugal force.

Let us call y the surplus of elevation given to the outward rail (fig. 30;) $2e$ being the breadth of the way, the inclination of the plane on which the wagons are placed, is $\frac{y}{e}$. On this plane, the gravity of a body, the weight of which is P, is expressed by

$$P \times \frac{y}{2e}.$$

This gravity, as we have seen, tends to make the wagons fall within the curve, while the centrifugal force pushes it without. If, therefore, we select the height y, such as may give

$$P \times \frac{y}{2e} = P \times \frac{V^2}{gr},$$

the train, in passing over the curve, will experience no derangement from its original position, because the gravity and the centrifugal force will equilibrate.

But, as for motives already explained, we require the wagon to be pushed aside, a certain quantity expressed by

$$\frac{ae\,\mathrm{D}}{2\,(r+e)}=\mu,$$

we must endeavour to find out what is the necessary inclination.

Let us then suppose the train already displaced as much as required. Let us imagine, for instance, that the train has been pushed from the position *ab* to the position *cd* (fig. 30;) that is to say, that the point of the inside wheel that was at *a* be come to *c*, at the distance μ from the first point, and that at the same time, the point of the outward wheel that was at *b*, be come to *d*. In this situation, the inclination of the plane on which the train is, will be

$$\frac{y}{2\,e-\mu}.$$

Moreover, the conical inclination of the wheels shows that on the outward side of the curve the wheel will have increased its diameter by a certain quantity, in consequence of the lateral deviation; while on the interior side, it will on the contrary, have diminished of an equal quantity. The tire of the wheel having a supposed inclination of $\frac{1}{a}$, a lateral motion represented by μ, must have produced on each wheel a difference in height represented by $\frac{\mu}{a}$. The effect of that variation of the wheels being to incline the wagon on one side, so that it is raised on one side of the quantity $\frac{\mu}{a}$; and lowered on the other of the same quantity $\frac{\mu}{a}$; the result is a total inclination of $\frac{2\mu}{a}$, which must thus be added to the inclination already produced by the difference of level between the rails.

Consequently, the outward side of the wagon will be raised above the interior side of a quantity equal to $y+\frac{2\mu}{a}$;

and as the base which separates the two bearing points is measured by $2e-\mu$, the final result is that the wagon will be in the same case as if it were placed on a plane, the inclination of which should be

$$\frac{y+\frac{2\mu}{a}}{2e-\mu}.$$

In order that the centrifugal force may maintain the wagon in that position without throwing it out or letting it fall in, that is to say, so that there may be an equilibrium between the gravity on the plane and the centrifugal force, we must have

$$P\times\frac{y+\frac{2\mu}{a}}{2e-\mu}=\frac{PV^2}{gr}.$$

or

$$y=\frac{V^2}{gr}(2e-\mu)-\frac{2\mu}{a}.$$

Substituting for μ its value, this equation becomes

$$y=\frac{eV^2}{gr}\left\{2-\frac{aD}{2(r+e)}\right\}-\frac{eD}{r+e}.$$

Knowing, then, the conical form and the diameter of the wheels, as well as the average velocity of the motion and the breadth of the way, this expression will give the surplus of elevation y that suits the radius of curvation r.

Let us suppose that we have to employ the dimensions of the railway and wagons of Liverpool; that is to say, that we have:

V, average velocity, 20 miles an hour, or 29.3 ft. per second.

$\frac{1}{a}$, inclination of the tire of the wheel, $\frac{1}{7}$.

e, half-breadth of the way, 2.35 ft.

D, diameter of the wheel at its right place on the rail, 3 ft.

If we wish to construct on that railway a curve of 500 ft. radius, on which the wagons may experience no additional resistance, the equation will give

$y = 0.236$ ft., or in inches, $y = 2.83$ in.

We must, therefore, for that curve, with that wheel and that average velocity, give a surplus of elevation of 2.83 in. to the outward rail.

Adopting the surplus of elevation of the rail deduced from that equation, we render impossible the first species of resistance, which the passage of the curves tend to produce. However, as we only destroy that resistance by a certain lateral deviation of the wagon, it might be feared that that deviation might go so far as to make the flange of the wheel rub against the rail, in which case we would only have substituted one resistance for another. This is, therefore, the point we have still to consider.

We have, until now, supposed the inclination $\frac{1}{a}$ of the tire of the wheel to be given *a priori*. But as it is on that inclination that depends the degree of deviation the wagon must undergo on the rails, it must evidently be such that, even on the most abrupt curve of the line, the lateral deviation of the wagon may never be considerable enough to bring the flange of the wheel in contact with the rail.

Now we have seen above, that the necessary lateral deviation is expressed by

$$\mu = \frac{aeD}{2\ (r + e)};$$

If, therefore, the wagons, have, for instance, a play of 2 in. on the way altogether; that is to say, if, in their regular position, the flanges of the wheels keep on each side at a distance of 1 in. from the rail, the greatest value of the deviation μ, must always be less than 1 in. By that greatest value of μ, we mean the deviation on the most abrupt curve of the line. Consequently, putting for r the radius of that curve, and for μ its maximum, 1 in. or $\frac{1}{12}$ of a foot, the equation will give the greatest value that can be given to the quantity a, or the least value of the inclination $\frac{1}{a}$.

For instance, on a line, the most abrupt curve of which

has 500 ft. radius, with wagons having wheels of 3 ft. diameter and a play of 1 in. on each side of the way, the equation shows that the least inclination one ought to give to the tire of wheel is $\frac{1}{12}$; but a more considerable inclination will answer, *a fortiori*.

On the Liverpool and Manchester Railway, the most abrupt curve, which is the one at the entrance of Manchester, has a radius of 858 ft. This curve would not require more than a conical inclination of $\frac{1}{12}$, and this would answer in all cases; but having said that a greater inclination will fulfil the same object, we are free to adopt a greater inclination, if it suits other purposes better.

It is customary to give an inclination of $\frac{1}{7}$. The motive for making it so considerable, is to prevent all possibility of the flange rubbing against the rail, either in case of a strong side wind, or in case of some fortuitous defect in the level of the rails, by which the wagons would be thrown on the lower rail. Having seen above that, with an inclination of $\frac{1}{12}$, there would be no danger of the flange rubbing in the curves, that danger will be still more impossible with an inclination of $\frac{1}{7}$.

We conclude that, with wheels having that inclination, the surplus of elevation of the rail which we have determined above, will correct the first species of resistance of the curves without creating the second, and that, consequently, the train will pass over the curves without any diminution of speed.

Section 2.—*A Practical Table of the Surplus of Elevation of the outward Rail in Curves, in order to annul the effect of those Curves.*

From what has been said, the surplus of elevation that must be given to the outward rail in the curves, is determined by the following formulæ:

$$y = \frac{eV^2}{gr}\left\{2 - \frac{aD}{2\,(r+e}\right\} - \frac{eD}{r+e}.$$

In this equation the signs have the following value:

D, diameter of the wheel, expressed in feet.

r, radius of the curve, expressed in the same manner.

e, half of the width of the way, expressed the same.

V, average velocity that is to be given to the motion, expressed in feet per second.

g, accelerating force of gravitation, expressed in feet per second, or $g = 32$ ft.

$\frac{1}{a} = \frac{1}{7}$; consequently, $a = 7$.

y, surplus of elevation to be given to the outward rail of the curve over the inward rail, expressed in feet and decimals of feet.

Solving these formulæ in the most usual cases on railways, we make out the following table, which dispenses with all calculations in that respect.

A PRACTICAL TABLE OF THE SURPLUS OF ELEVATION TO BE GIVEN TO THE OUTWARD RAIL IN THE CURVES, IN ORDER TO ANNUL THE RETARDING EFFECT OF THE CURVES.

Designation of the wagons and the way.		Radius of the curve in feet.	Surplus of elevation to be given to the rail, in inches, the velocity of the motion in miles, per hour, being		
			10 miles.	20 miles.	30 miles.
		ft.	in.	in.	in.
Wagon with wheel -	3 ft.	250	1.14	5.60	12.99
Way - - -	4.70 ft.	500	0.57	2.83	6.56
Play of the wagon on		1000	0.29	1.43	3.30
the way, 1 in. or -	0.083 ft.	2000	0.15	0.71	1.65
Inclination of the tire		3000	0.10	0.47	1.10
of the wheel - -	$\frac{1}{7}$	4000	0.07	0.36	0.83
		5000	0.06	0.28	0.66

ARTICLE II.

OF THE INCLINED PLANES.

SECTION 1.—*Of the Resistance of the Trains on Inclined Planes.*

Inclined planes are a great obstacle to the motion on railways.

As soon as the trains reach these inclined planes, they offer a considerable surplus of resistance, on account of the gravity of the total mass that must be drawn up the plane.

Let us suppose a train of 100 t. drawn by an engine. Having seen that on a level the friction of the wagons produces a resistance of 8 lbs. per ton, the power required of the engine will be 800 lbs. when travelling on a level. But let us suppose the same train ascending an inclined plane at $\frac{1}{100}$. On that plane, besides the resistance owing to the friction of the wagons, a fresh resistance occurs, which is the gravity of the total mass in motion on the plane. That gravity is the force by virtue of which the train would roll back if it were not retained; and it is equal to the weight of the mass divided by the number that indicates the inclination of the plane. If, therefore, in this case, the load of 100 t. is drawn by an engine weighing 10 t., the total mass placed on the inclined plane will be 110 t. or 246,400 lbs.; and thus its gravity on the inclined plane, at $\frac{1}{100}$ will be $\frac{246400}{100}$ lbs. = 2,464 lbs. The surplus of traction required of the engine, on account of that circumstance, is, therefore, 2,464 lbs., and, as we have seen that on a level 1 t. load is represented by 8 lbs. traction, we also see that those 2,464 lbs. represent the resistance that would be offered by a load of 308 t. on a level. Consequently, the engine, which, before, drew 100 t.

must now draw 408 t., or at least must exert the same effort as if it drew 408 t. on a level.

This is the manner in which the calculation of the resistance on inclined planes must be established; and we have entered into those particulars, because it frequently happens that in making the calculation, the gravity of the load is alone considered, without taking into account the gravity of the engine, which ought also to enter for its share.

In speaking of the fuel, we shall see that the inclined planes of the Liverpool Railway, which at first sight appear quite insignificant, oblige, however, the engines to a surplus of work, which amounts to a sixth part of what they would have to do on a level. By this we see how important it is, in establishing a railway, to keep it on as perfect a level as possible. It frequently happens that, by avoiding to level a part of the road, that is to say, to cut through a hill, or to form an embankment through a valley, a great economy is expected. This is, however, a great mistake, for, in most instances, the only economy is that of the first outlay, whereas, the annual augmentation of expense surpasses by far the interest of the capital saved; so that, instead of an economy, we have in reality a greater expense. This additional expense may even, in some cases, go so far as to paralyze completely all the advantages of the undertaking.

In suffering inclined planes to subsist on a line of railway, it not only becomes impossible to lower sufficiently the freight of the goods; but, what is much more important, frequent accidents occur while descending those steep acclivities, the least inconvenience of which is to destroy public confidence in the safety of the conveyance. It is, therefore, necessary to lay down as a principle, that the end to be aimed at, in the construction of a railway, is not only to make a smooth road, but likewise a level one. It is, besides, the only way to apply with efficacy the use of locomotive engines.

When, however, it has been impossible to avoid the in-

clined planes, and when the use of stationary engines has been rejected on account of the interruption they unavoidably cause in the service, there are only two ways that can be resorted to. The loads must either be regulated so that they may not exceed the power of the engine in going up the plane, or it is necessary to give the engines the help of one or more others, according to what is required.

On the Liverpool Railway the trains of coaches never being very heavy, are seldom above the power of the engines on the most inclined parts of the line, viz. in the two acclivities of $\frac{1}{96}$ and $\frac{1}{89}$. In general, therefore, the engines ascend these inclined planes without help; and during the rest of the trip, on the level or descending parts of the line, their speed is regulated by partially shutting the regulator.

The trains that are too heavy for a single engine, as are commonly those of wagons, are helped in passing the plane by an engine stationed at the foot of the acclivity, and especially intended for that use. This engine is, consequently constructed for a slow motion and a considerable power. The cylinders have 12 or 14 in. diameter, with the usual stroke of 16 in., and the wheels have only 4 ft. 6 in. Besides, in order to have more adhesion, the weight of the engine is 12 t. and the four wheels are coupled. These additional engines, working less than the others, require also, in general, much less repairs.

On the Darlington Railway, the acclivities are much too numerous for an additional engine to be placed at each of them. The load of the engine must therefore be limited so that it may ascend with that load the most inclined of the planes.

The locomotive engines acquire, however, a considerable augmentation of power, at the moment of their passage on an inclined plane, because their speed being suddenly considerably reduced, the cylinders consume a smaller quantity of steam. The fire, strongly excited by the preceding ra-

pidity of the engine, continuing to furnish the same quantity of steam, a great part of it must escape through the valve. But the passage of the valve is too narrow to emit freely all that steam. Besides, the spring that presses on the valve opposes more and more resistance, in proportion as the steam tends to raise it higher, in order to get a wider passage for itself. The consequence is, that the steam, not being able to escape as quickly as it is generated, suffers an increase of pressure in the boiler.

This increase of pressure evidently depends on several circumstances: the size of the valve, the evaporating power of the boiler, the previous excitation of the fire, and finally the length of the lever at the extremity of which the spring-balance acts. In some engines this increase may amount to 10 lbs. per square inch, as we have remarked in speaking of the pressure.

In that case, if the usual effective pressure of the engine be 50 lbs. per square inch, it may, on ascending the inclined plane, increase to 60 lbs., that is to say, in the proportion of $\frac{1}{5}$, which is considerable. This must, therefore, be taken into account when it is required to calculate the load the engines are able to draw on these planes. But it is necessary to observe that this is effectual only when the inclined planes are not of too considerable an extent, because, in that case, the fire ceasing to be excited in the same proportion, the surplus of effect will be reduced. The weight of the engine must, besides, always give sufficient adhesion of the wheel to the rail, as we shall explain in the following Chapter.

There is also another circumstance in which the engines are obliged to exert an additional effort. That is at the moment of starting. We have seen, in fact, that the power which, when the motion is once created, need only to be constantly equal to the resistance, must, on the contrary, surpass it at the instant that it is to put the mass in motion. The reason is plain: in the first case, it is only necessary to maintain the speed; in the other, it must be created and

maintained. It is this additional effort on the part of the moving power which is improperly called *vis inertiæ*, because it is attributed to a particular resistance residing in the mass.

The starting is, therefore, a difficult task for a locomotive engine heavily loaded. However, at that moment the engine acquires, as well as on the inclined planes, a considerable increase of power. Here again the slowness of the motion produces two effects. The pressure in the cylinder grows equal to the pressure in the boiler, which is itself augmented by the effect of the spring-balance. But, notwithstanding this twofold advantage, the difficulty of starting still remains so great for considerable loads, that we should always advise giving in that point a slight declivity to the way. By that means the trains would be set in motion with more ease at the departure, and it would not be necessary at their arrival to make use, in order to stop them, of the powerful brakes, the effect of which is certainly as destructive to the wheels of the wagons as to the rails.

Section 2.—*Practical Table of the Resistance of the Trains on Inclined Planes.*

In the preceding paragraph, we have seen in what manner the resistance of the trains on the inclined planes must be calculated. The following table presents the result of that calculation in the cases which occur the most frequently on the railways.

It is clear that, by the weights inscribed in the following table, it is only intended to show the resistance offered by the train, and not the weights the engines are able to draw, those weights being limited either by the power of the engine, as we have explained elsewhere, or by its adhesion, as shall be mentioned in the following Chapter.

This table, assimilating the trains drawn on inclined planes to trains drawn on a level, gives the means to learn by the

former tables, either the loads the engines will be able to draw on given inclinations, or *vice versa*, the inclined planes the engines will be able to ascend with given loads.

A PRACTICAL TABLE OF THE RESISTANCE OF THE TRAINS ON INCLINED PLANES.

Designation of the Engine.	Weight of the trains in gross tons, tender included.	Load in gross tons, which on a level would offer the same resistance, the inclination of the plane being					
		$\frac{1}{500}$	$\frac{1}{400}$	$\frac{1}{300}$	$\frac{1}{200}$	$\frac{1}{150}$	$\frac{1}{100}$
Engine weighing 8 t.	25	44	48	56	71	87	117
	50	83	91	105	131	158	212
	75	122	133	153	191	230	307
	100	161	176	201	251	302	402
	125	200	218	249	311	373	497
	150	239	261	298	371	445	592
Engine weighing 10 t.	25	45	50	58	74	91	123
	50	84	93	107	134	162	218
	75	123	135	155	194	234	313
	100	162	178	203	254	306	408
	125	201	220	251	314	377	503
	150	240	263	300	374	449	598
	175	279	305	348	434	521	6[illegible]3
	200	318	348	396	494	592	78[illegible]
Engine weighing 12 t.	25	46	51	60	77	95	129
	50	85	94	109	137	166	224
	75	124	136	157	197	238	319
	100	163	179	205	257	310	414
	125	202	221	253	317	381	509
	150	241	264	302	377	453	604
	175	280	306	350	437	525	699
	200	319	349	398	497	596	794
	225	358	392	446	557	668	889
	250	397	434	494	617	740	984

CHAPTER VIII.

OF THE ADHESION.

Section 1.—*Measure of that Force.*

The series of experiments we have described above, on the velocity and load of the engines, solves also another question in regard to the motion of locomotive engines, of which we have not yet spoken. That is the adhesion of the wheel to the rails.

We have remarked in describing the engine, that the power of the steam being applied to the wheel, the engine is in the same situation as a carriage which is made to advance by pushing at the spokes. Thus, as in that action, the only fulcrum of the moving power exists in the adhesion of the wheel to the rail, if that adhesion is not sufficient, the force of the steam will indeed make the wheels turn, but the wheels, slipping on the rails instead of adhering to them, will revolve, and the engine will remain in the same place.

The more considerable the train the engine draws, the more power it must employ, and the more resistance it must consequently find in the point on which it rests, for executing the motion. It was therefore to be feared, that with considerable trains, the engines would be unable to advance; not that the force would be wanting in the moving power itself, but in the fulcrum of the motion.

The experiments related above, establish the measure of that adhesion in the fine season of the year. Among all these experiments, not one is to be found where the motion has been stopped or even slackened for want of adhesion, and nevertheless we see loads that amount to more than 200 t.

If we take, for instance, the first experiment made with the Fury, on July 24; during a part of the journey, that engine drew 244 t. The engine advancing with that load, the adhesion must necessarily have been sufficient. Now the weight of the Fury is 8.20 t., and that weight is divided in such a manner, that 5.5 t. are supported on the two hind wheels, which are the only working wheels, the others not serving to push the engine forward, but only to carry it. We have thus a weight of 5.5 t., drawing 244 t., or a load 44½ times as considerable as itself. The result of this is, that an engine having its four wheels coupled, and which consequently adheres by its whole weight, is able to draw a load 44½ times its own mass.

We have said that the Fury engine adhered only by two of its wheels. On the Liverpool Railway that disposition is generally adopted for all trip engines, because the adhesion of two wheels is sufficient for the loads they have to draw. As for the helping engines, they work by the adhesion of their four wheels, as has been said elsewhere. The Atlas is the only one of the former class that differs from the others in that respect. This engine has six wheels, four of which are of equal size, and worked by the piston. The two others, which are smaller, and have no flange, can be raised out of contact with the rails, by the action of the steam on a moveable piston. That ingenious arrangement, which may have more than one useful application, in permitting the weight of an engine to be distributed upon six wheels, without making the engine more embarrassing than if it had only four, is due to Mr. J. Melling, of Liverpool, who, in this instance, made use of it in order to give the engine a much larger fire-

box, and, consequently, the power of generating a greater quantity of steam.

We have now expressed the adhesion, by giving the measure of its effects; but the power itself may be expressed in a direct manner. The load of 244 t. produced a resistance, or required a traction of 1,952 lbs.; the adhesion was thus equal at least to, 1,952 lbs., else the wheel would have turned without advancing. Now the adhering weight was 5.5 t., or expressed in pounds 12,320 lbs.; we see then that the force of adhesion was equal to about $\frac{1}{6}$ of the adhering weight. Considering that every 8 lbs. force corresponds with the traction of a ton on a level, this expression is exactly similar to the first.

In winter when the rails are greasy and dirty, in consequence of damp weather, the adhesion diminishes considerably. However, except in very extraordinary circumstances, the engines are always able to draw a load of 15 wagons, or 75 t., tender included, that is to say, 14 times their adhering weight. In other words, the resistance of 75 t. being 600 lbs., the force of adhesion is always at least $\frac{1}{20}$ of the adhering weight.

Adhesion being indispensable to the creation of a progressive motion, two conditions are necessary in order that an engine may draw a given load. 1st. That the dimensions and proportions of the engine and its boiler enable it to produce on the piston, by means of the steam, the necessary pressure, which constitutes what is properly termed the power of the engine; and, 2d, that the weight of the engine be such as to give a sufficient adhesion to the wheel on the rail. These two conditions of power and weight must be in concordance with each other; for, if there is a great power of steam and little adhesion, the latter will limit the effect of the engine, and there will be steam lost; if, on the other hand, there is too much weight for the steam, that weight will be a useless burden, the limit of load being in that case marked by the steam.

SECTION 2.—*Of the Engines employed on Common Roads.*

The considerable loads that have been drawn by the engines in the experiments described above, ought to remove the fears of such persons as suppose that the wheels of locomotive engines on railways are constantly apt to slip, and who endeavour to remedy that imaginary defect by employing the engines on common roads, without having ascertained whether the adhesion will be more considerable.

We see here a locomotive engine on a railway, drawing 244 t. by the force of its steam, and not less than 75 t. by its adhesion. Its loads are thus always comprised between those two limits.

On a common road, where the resistance of traction is very considerable, not one of the above-mentioned engines would be able, by the force of its steam, to draw a weight of 75 t., much less ever to attain 244 t. The loads will therefore always, and in every circumstance, remain below what they would be on a railway. Of what importance is it, in fact, whether the moter gains in regard to adhesion, which is only an inert force, if the power of the steam do not enable it to profit of that advantage?

We say that an engine that draws on a railway a load of 75 t. *at least*, will never be able, on a common road, to draw that same load *at most*.

Let us in fact examine the same engine, with the same weight and same pressure, placed in those two different circumstances.

The experiments made by Mr. Telford, on the draft of carriages on different sorts of roads, prove that on the road from Liverpool to Holyhead, *the best in England*, the force of traction necessary to draw a weight of one ton is as follows:—*

* Report of the Holyhead Road Commissioners.

	lbs.
1st. On a well-made pavement - - - - -	33
2d. On a broken stone surface on old flint road - -	65
3d. On a gravel road - - - - - -	147
4th. On a broken stone road, upon a rough pavement foundation - - - - - - -	46
5th. On a broken stone surface upon a bottoming of concrete, formed of Parker's cement and gravel -	46
Mean - - -	67

On a railway, a ton requires only 8 lbs. traction. Thus, on the Holyhead road, the traction of a ton requires eight times as much force as on a railway.

The consequence is, that the Fury engine, for instance, which by the effect of its 65 lbs. effective pressure, was able to draw on a level 244 t., would in no circumstance, even on the excellent Holyhead road, be able at the same pressure to draw more than $\frac{1}{8}$ of that load, or 30 t.

Thus its *maximum* load on a common road would only be the $\frac{3}{5}$ of its *minimum* load on the railway.

To which must still be added, that the resistance of the engine, in the case of its progress on a common road, will be, like the resistance of the wagons, considerably augmented. It will therefore be obliged, in order to move itself, to consume a much greater portion of its own power, which will diminish in the same proportion the 30 t. it might else have drawn.

We see that on a common road, the resistance of the carriages puts much quicker a stop to the useful effect than the adhesion does on a railway; and, that, under all circumstances, the advantage in regard to the load is in favour of the engines on railways.

But there is another consideration that appears to militate in favour of what is called steam-carriages, that is to say; locomotive engines employed on common roads; that consideration is the expense of constructing a railway which is thus avoided. A considerable economy is expected to be

made by that means. The construction and keeping in repair of the railway, is in fact a very heavy expense. The capital laid out for that will be entirely avoided. But, at the same time, the chief advantage of the undertaking will be lost.

Why demur to lay out capital, if a considerable profit is to be derived from it? Why save the first expense, if the consequence is the necessity of spending more annually than the interest of the capital saved?

This is exactly the present case. The construction of a railway is undoubtedly expensive; but it is the principal element of success. It is money employed to level the road, in order not to have any difficulty afterwards in conveying the goods, and to begin from that moment to reap the profits. What would be said to a man who should propose to cross the fields in order to avoid the constructing of roads? The answer would be, that the loss in freight would be greater than the expense of construction.

The same is true in regard to railways. If there be an advantage in constructing them for horses, as an experience of sixty years' prosperity has sufficiently demonstrated, how is it possible that there should be none for the use of locomotive engines or any other moter? Whatever advantage these engines may offer on common roads, they must necessarily present a much greater one on railways.

It may appear surprising to see a steam engine on a common road draw two or three stage coaches with 12 or 15 passengers in each. But the Liverpool engines at the time of the races have drawn as much as 800 persons in a single train, at a speed of 15 miles an hour.

It will perhaps be said, that steam-carriages are able to draw more than three stage-coaches. As yet, however, none have been found that have done more. The greatest part of them do not even carry more than 18 or 20 passengers. It is easy to see the cause that puts so soon a limit to

their load. There exists no common road without considerable acclivities. As they must be overcome, it is necessary to give to the engine only the load which it can take over the steepest of those ascents. Now, on an acclivity of $\frac{1}{12}$, the weight of three stage-coaches, or 9 t., increased by the weight of the engine, presents, on account of the gravity, a resistance equal to that which 45 t. or 15 stage-coaches would offer on a level. A steam-engine that is to draw three stage-coaches during a journey of some length, must therefore be able to draw 15 loaded stage-coaches on a level common road. This is all that can be supposed, even admitting improvements, for that force corresponds with 120 stage-coaches on a railway. We must take therefore two or three stage-coaches at most, as the regular load of these engines.

But the levelling, which is the result of the expense attending the construction of a railway, renders those same engines capable of drawing 40 loaded stage-coaches or wagons. This is thus 12 or even 20 times as much. To do the same work on a common road, 12 times as many engines will consequently be required at once, with 12 times as many engine-men and fire-men. Considering also the disadvantage there is for the engines, in respect to fuel in drawing small loads, we may confidently calculate that the expense for fuel will be doubled. Of this we will be the more convinced, if we take into account the surplus of power necessary to move the engine itself on a road full of asperities.

Besides, the repairs of the engines are, even on railways, a considerable expense. At Liverpool of the 30 engines belonging to the company, ten only are in *activity* on the line for the conveyance of goods and passengers. The effective work is eight or ten hours a-day, and the expense for maintaining in activity those ten engines, amounts to more than £18,000, or £1,800 a-year for each of them. These expenses are paid and become a source of profit, because on

a railway the engines draw considerable trains; but it would not be the same thing if the trains were reduced, or, in other words, if a greater number of engines, were required to do the same work. Moreover, if the engines, instead of sliding without jolts on the smooth surface of a railway, were obliged to run on the rough soil of our roads, how great would not be the expense of repairs. And we have 12 times as many engines to repair.

Outlay and interest of capital for engines, salary of engine-men and assistants, fuel, repairs, all these articles will soon have absorbed the expected economy.

Besides, the chief advantage of such undertakings, consists in the speed with which the haulage is executed. When the 29½ miles between Liverpool and Manchester were travelled in four hours, there were about 450 passengers going daily from one of those towns to the other. At present when, thanks to locomotive engines, the journey is completed in a hour or an hour and a half, there are 1,200 passengers a-day. The speed has the greatest share in the creation of that profit. It must be given up if the engines are only to run eight or ten miles an hour.

Now, the 8 or 9 t. that the locomotive engines weigh on railways, allow us to give them a sufficient extent of boiler to generate a certain quantity of steam per minute, and consequently a certain speed. If the nature of the road obliges us to reduce the weight of the engine to 3 t. only, with the necessity of making all its different parts stronger, on account of the jolts on a rough surface, there will naturally be less heating surface in the boiler, and consequently less possible speed. And, in fact, the steam-coaches scarcely do more than eight or ten miles an hour.

As a last reflection, we shall add, that until the present moment the success of locomotive engines on common roads, continues, as a speculation, to be very uncertain, whilst the prosperity of railways, whatever be the moving power, is

demonstrated by their continued extension. Steam-coaches may be improved, but, we repeat, whatever be the advantages they may offer on a common road; it is not to be contested that, by employing them on a railway, those advantages will be infinitely greater.

CHAPTER IX.

OF THE FUEL.

Section I.—*Of the Consumption of Fuel in Proportion with the Load.*

We have still an important article to discuss. That is the fuel.

From what we have said above, the steam, generated in the boiler at whatever pressure it may be, takes, in passing into the cylinder, a pressure exactly determined by the resistance on the piston. The mode of action of the engine, is thus limited to the transformation of a certain quantity of steam drawn from the boiler, and consequently at the pressure of the boiler, into steam at a lower pressure and of a proportionally greater volume.

Let us suppose the same engine, with the same pressure in the boiler, and travelling the same distance with two different loads. The distance travelled being the same, the number of turns of the wheel, and consequently of strokes of the piston or cylinders of steam expended during the journey, will be the same in the two cases. If the load had been the same, there would also have been identity in the nature of the steam expended. But as the loads differed, the same number of cylinders will indeed have been expended, but the degree of the steam in the cylinders will be different in the two cases.

Then the expense of moving power will be in one case a certain volume of steam at the pressure R, for instance, and in the other case the same volume at the pressure R′.

The pressure of the steam in the boiler being supposed the same in the two experiments, its temperature will also be the same. As the temperature experiences no reduction during its passage to the cylinders, the pipes and the cylinders themselves being immersed in the boiler, or surrounded by the flame of the fire-place, the temperature of the steam in the cylinders will be the same in the two cases.

Thus the volume and temperature of the steam expended during the journey will be the same in both circumstances. The pressure of the steam in the cylinder will alone have undergone a change. Consequently the mass or weight of steam expended, will be in each case in the ratio of the pressure in the cylinder.

The weight of the steam being equal to that of the water that generated it, the weights of water evaporated will then be to each other as the pressures in the cylinder, or, in other words, as the resistances on the piston. Besides, as the water is first transformed into steam at the pressure of the boiler, that is to say, in both cases into steam at the same degree of pressure, it follows also that the quantities of fuel necessary for the evaporation, will be to each other as the pressures or total resistances on the piston.

This shows that the consumption of fuel is independent of the speed, and that it depends only on the resistance on the piston.

If in the two journeys, we consider, the pressure happens not to be identically the same in the boiler, there will be a little more fuel consumed in that case where the pressure has been the greatest, because the pressure could only increase in consequence of an increase of temperature. But as degrees of pressure very distant from each other are produced by very similar temperatures, the difference of consumption

occasioned by that circumstance will be of little importance, and will not be perceived in practice.

This principle gives the proportion of the consumption of fuel for the same engine with different loads, and may thus serve to determine its consumption in all circumstances, as soon as it is known in one determined case.

If for instance Q and Q′ are the quantities of fuel expended with two given loads, the resistance on the piston with the first of these loads being expressed by R, and with the second by R′, we shall have

$$\frac{Q}{Q'}=\frac{R}{R'}.$$

But we have already calculated the resistance R on the piston of an engine. We have seen (Chap. V. Art. 11.) that M being the load expressed in tons, tender included; F the friction of the engine without load; d the diameter of the cylinder; D the diameter of the wheel; l the length of the stroke; ρ being the atmospheric pressure per unit of surface, n the resistance of the load per ton, and δ the additional friction of the engine per ton of load, that resistance is

$$R=[F+(\delta+n)M]\frac{D}{d^2l}+\rho;$$

Thus, for a different load drawn by the same engine, we shall have

$$R'=[F+(\delta+n)M']\frac{D}{d^2l}+\rho;$$

consequently,

$$\frac{Q}{Q'}=\frac{[F+(\delta+n)M]\frac{D}{d^2l}+\rho}{[F+(\delta+n)M']\frac{D}{d^2l}+\rho}.$$

This equation can be written in the following form:

$$\frac{Q}{Q'}=\frac{M+\left[\frac{\rho d^2l}{(\delta+n)D}+\frac{F}{\delta+n}\right]}{M'+\left[\frac{\rho d^2l}{(\delta+n)D}+\frac{F}{\delta+n}\right]}.$$

So that the expression $\left\{\frac{\rho d^2 l}{(\delta+n)D}+\frac{F}{\delta+n}\right\}$ being calculated once for all the given dimensions of the engine, nothing more will be necessary than to add that quantity to M and M′, in order to have the required proportion of Q to Q′.

Let us suppose, for instance, that we have an engine similar to the 11-inch cylinder engine of Liverpool, viz:

F, friction of the engine without load	=	110 lbs.
d, diameter of the cylinder 11 in., or in feet	=	0.917 ft.
D, diameter of the wheel - - -	=	5 ft.
l, length of the stroke 16 in., or in feet -	=	1.33 ft.

As besides we have

ρ, atmospheric pressure per square foot	=	2,117 lbs.
n, resistance of the load per ton - -	=	8 lbs.
δ, additional friction of the engine per ton of load - - - - -	=	1 lb.

For this case we shall have

$$\frac{\rho d^2 l}{(\delta+n)\,D}+\frac{F}{\delta+n}=65.$$

In the case of a 12-inch cylinder engine, with 152 lbs. friction, like the ATLAS, the value of this quantity would be 80.

And, finally, for the VESTA, with $11\frac{1}{8}$-inch cylinders and 187 lbs. friction, the same quantity is 75.

Thus, in the case of those different sorts of engines, we shall have for the quantity of fuel expended with two different loads M and M′,

$$\frac{Q}{Q'}=\frac{M+65}{M'+65},$$

or

$$\frac{Q}{Q'}=\frac{M+80}{M'+80},$$

or finally

$$\frac{Q}{Q'} = \frac{M + 75'}{M' + 75}.$$

In these expressions M stands for the load, tender included; the weight of the tender is meant, therefore, to be added to the load, if it was not included in it from the first. We easily perceive that the quantity $\frac{F}{\delta + n} + \frac{\rho d^2 l}{(\delta + n)D}$ is nothing but the friction of the engine and the atmospheric pressure referred to the velocity of the engine, and represented by the number of tons that would offer an equivalent resistance. Thus the number M of tons, added to that quantity, represents the total resistance overcome, by the engine. Consequently the principle established above amounts to this: that the power applied is in proportion to the *total* resistance to be overcome, as was naturally to be expected.

This invariable quantity, which must be added to the load, expresses, as we have said, the aggregate inert resistance of the engine, or, if we may be permitted to use that expression, the *constant vis inertiæ* of the engine. As this quantity differs for each engine, and as it must be calculated separately for each of them, we shall join here a table which will show its value, superseding thus the necessity of calculating it, for the engines most commonly used on railways.

A TABLE OF THE CONSTANT VIS INERTIÆ OF THE ENGINES, NECESSARY TO DETERMINE THE CONSUMPTION OF FUEL WITH DIFFERENT LOADS.

Designation of the Engine.		*Constant vis inertiæ,* expressed in tons.
Engine with cylinders 11 in., or in feet	0.917 ft.	66 t.
stroke 16 in., or - -	1.33 ft.	
wheel - - - -	5 ft.	
friction - - -	120 lbs.	
Engine with cylinders 12 in., or -	1 ft.	80 t.
stroke 16 in., or - -	1.33 ft.	
wheel - - - -	5 ft.	
friction - - -	150 lbs.	
Engine with cylinders 13 in., or -	1.083 ft.	92 t.
stroke 16 in., or - -	1.33 ft.	
wheel - - - -	5 ft.	
friction - - -	165 lbs.	
Engine with cylinders 14 in., or -	1.166 ft.	105 t.
stroke 16 in., or - -	1.33 ft.	
wheel - - - -	5 ft.	
friction - - -	180 lbs.	
Engine with cylinders 12 in., or -	1 ft.	107 t.
stroke 18 in., or - -	1.50 ft.	
wheel - - - -	5 ft.	
friction - - -	165 lbs.	

SECTION 2.—*Experiments on the Quantity of Fuel consumed by the Engines.*

The above formula, which is of easy application, gives the absolute quantity of fuel required by an engine in all circumstances, provided the consumption of the engine in a given case be known.

The only thing necessary, will therefore be, to make one experiment on the fuel consumed by the engine with a given load, which will be the data of the problem.

Evidently between two different engines, this first data will differ according to the particular construction of each engine, and chiefly according to the extent of heating surface of its boiler. The following experiments were therefore undertaken on the Liverpool and Manchester Railway, in order to obtain a knowledge of this data, and likewise to verify the theoretical principle exposed above.

In these experiments the tender was first carefully emptied, then the coke was accurately weighed and put into the tender. The fire-place of the engine was besides filled with fuel, up to the lower part of the door. At the end of the experiment, the fire-place was again filled to the same height, and the coke remaining in the tender was weighed with the same care as at setting off.

As an engine that ascends alone, with its train, an inclined plane exerts necessarily a greater effort than if at that moment it were helped by an additional engine, we have put down whether the engine was helped or not in going up the plane. We have also inscribed the state of the weather and the temperature of the water in the tender, in order that those circumstances might be taken into consideration.

In these experiments, the co-operation of the persons attached to the establishment was often necessary. We must particularly mention Mr. J. Dixon, the resident engineer, to whom we are indebted also for his accurate levelling of the road, and many other pieces of information obligingly communicated to us.

EXPERIMENTS ON THE QUANTITY OF FUEL CONSUMED.

Name of the Engine.	Date of the experiment.	Nature and weight of the load not including the tender.		Time of the trip of 29¼ miles.	Delays on the road, not included in the above time.	Average effective pressure in lbs. per square inch.
	1834.		tons.	h. m.	m.	lbs.
ATLAS, from Liv. to Manch.	23 July	40 wagons - -	190.00	3. 2	15	53.7
Do. Do.	9 July	25 do. - -	123.13	1.48	12	53
Do. Do.	4 Aug.	25 do. - -	122.64	1.58	0	53
Do. Do.	14 July	25 do. - -	118.90	1.31	19	61.5
Do. Do.	11 July	25 do. - -	117.61	1.41	5	53
Do. Do.	28 June	25 do. - -	113.90	1.50	5	53
Do. Do.	16 July	20 do. - -	94.66	1.25	23	53.5
Do. Do.	17 July	15 do. - -	65.40	1.27	3	54
Do. from Manch. to Liv.	31 July	8 loaded wagons and 4 empty	35.15	1.54	0	30
Do. Do.	17 July	3 loaded wagons and 8 empty, and 2 wagons on a part of the road.	25.30	1.26	3	54.5
VESTA, from Liv. to Manch.	5 July	20 wagons - -	92.75	1.42	5	53
Do. from Manch. to Liv.	1 Aug.	5 loaded wagons and 5 empty	28.15	1.5½	0	51
VULCAN, from Liv. to Manch.	1 July	20 wagons - -	97.70	1.37	3	54.5
Do. from Manch. to Liv.	22 July	9 first class carriages	34.07	1.17	3	54.5
LEEDS, from Liv. to Manch.	15 Aug.	20 wagons - -	83.34	1.35	0	54
Do. from Manch. to Liv.	15 Aug.	8 do. of which 1 at half way	32.01	1.17	3	49
FURY, from Liv. to Manch.	24 July	10 do. - -	51.16	1.30	0	60
Do. from Manch. to Liv.	24 July	10 do. - -	43.80	1.35	0	59
JUPITER, from Liv. to Manch.	16 July	8 first class carriages	33.09	1.12	3	53
Do. from Manch. to Liv.	16 July	7 do. do.	33.09	1.12	4	53
FIREFLY, from Liv. to Manch.	26 July	8 do. do.	36.40	1.35	5	44
Do. from Manch. to Liv.	26 July	8 do. do.	36.40	1.18	5	49
		Sum -	1605.65	"	"	"

BY THE LOCOMOTIVE ENGINES, WITH GIVEN LOADS.

Coke of prime quality consumed during the journey.	Coke per ton per mile on a level, help deducted on incl. plane.	Accessory circumstances.		
		Help on the inclined plane.	Temperature of the water in the boiler.	State of the weather.
lbs.	lbs.			
1596	0.28	Help.	Water cold in the tender.	Calm weather.
1102	0.30	Help.	Water lukewarm in the tender.	"
1224	0.34	Help.	Water cold in the tender. *The connecting rods of the wheels too tight.*	Fair and calm weather.
1118	0.32	Help.	Water cold in the tender.	Fair and calm weather.
1136	0.33	Help.	Water lukewarm in the tender. *One piston too slack.*	"
1104	0.33	Help.	Water rather hot in the tender.	"
1081	0.39	Help.	Water a little lukewarm in the tender.	Calm weather.
1012	0.52	Help.	Water very hot in the tender. *The axle-box of one of the wagons too tight.*	Fair and calm weather.
881	0.73	No help.	"	"
720	0.82	No help.	Water very hot in the tender.	Fair and calm weather.
916	0.33	Help.	Water hot in the tender.	Calm weather.
774	0.80	No help.	Water very hot in the tender.	Fair weather, moderate wind in favour of the motion.
			The engine is still a little stiff. It comes out of the repair-yard.	
1071	0.37	Help.	Water lukewarm in the tender.	Calm weather.
664	0.56	No help.	Water cold in the tender.	Fair weather, very light wind against the motion.
897	0.36	Help.	Water rather lukewarm in the tender.	Fair and calm weather.
690	0.62	No help.	Water very hot in the tender.	Fair and calm weather.
806	0.46	No help.	Water cold in the tender.	Fair and calm weather.
746	0.49	No help.	Water cold in the tender.	Fair weather, side wind tolerably strong by intervals.
742	0.76	Help.	Water almost cold in the tender.	Fair and calm weather.
836	0.94	Help.	"	Fair weather, moderate wind contrary to the motion.
879	0.82	Help.	Water almost cold in the tender. *The engine is not in a good condition.*	Fair weather.
870	0.81	Help.	" *The engine is not in a good condition.*	Rainy weather, wind tolerably strong against the motion.
20865	"			

In examining these experiments, we find that neither the pressure in the boiler, nor the velocity of the motion, have any remarkable influence on the result. This fact was already indicated by theory.

We also remark the advantage that is found, in respect to fuel, in making the engines, whenever it is possible, draw the greatest loads their power will permit. For instance, the Atlas, drawing a load of 25 t., consumed 720 lbs. coke, whereas, in drawing 190 t., or a load eight times as great, it only consumed double the quantity of coke. This difference must evidently, as we have explained above, be attributed to the expense of power necessary in each case, in order to overcome the resistance of the atmosphere, the engine, and its tender.

We must add, that in those experiments the coke employed was of prime quality, or *Worsley coke*, which is prepared on purpose for iron-foundries. When gas-coke is used, the engines consume about 12 per cent. more, without reckoning the loss resulting from the friability of that combustible. It has moreover been ascertained, that the sulphurous parts it contains are highly destructive of metals. For that reason its use had been completely given up on the Liverpool Railway, notwithstanding its low price.

In making use of coals of good quality, the quantity required is nearly the same as that of good coke; but this combustible has in regard to the preservation of the engine, the same defects as gas-coke.

Respecting the distance travelled by the engine in these experiments, the railway from Liverpool to Manchester is generally reckoned 30 miles long, and considered a level; but as a greater degree of accuracy is required in the calculation, and as we wish to deduce from these experiments the really corresponding consumption of coke on a level-railway, we must reckon as follows.

One part of the line travelled by the locomotive engines is 29½ miles long. If we divide it in three parts, we see that

1 t. drawn from one end of the railway to the other, opposes the following resistances. (See the section of the railway, Chap. V. Art. VII. § 1.)

	ton.	miles.
1 t. at 26½ miles, on nearly a level - -	1 at	26½
1 t. at 1½ mile, ascending $\frac{1}{96}$ or $\frac{1}{89}$, equal (friction and gravity) to 4 t. drawn to the same distance on a level, or 1 t. at 6 miles	1 at	6
1 t. at 1½ mile, descending by the sole force of the gravity - - - - -	0	0
Sum - - - -	1 at	32.5

Thus when the engines ascend the plane without help, the work they actually do is equal to the traction of a similar load to a distance of 32.5 miles on a level.

If they ascend the plane with the help of one or more other engines, their share of the load in ascending is on an average only ⅓ of the whole on the plane, and thus the work they do is equal to the traction of their load to $26.5 + 2 = 28.5$ miles.

This does not include the surplus of resistance owing to the gravity of the engine and its tender in going up the plane. Their average weight being together from 13 to 14 t., the gravity of which on the plane is equal to the resistance of about 40 t. on a level, we see that this fresh effort required of the engine, equals the traction of 40 t. to a mile and a half, which is the length of the acclivity. If, therefore, the train itself weighs 30 t. without the tender, as is the case with engines that are not helped by additional ones, the work is equal to the traction of that train 2 miles more than the length of the line. If, on the contrary, the load weighs 60 or 80 t., as is in general the case with engines that are helped on the inclined planes, the additional traction of 40 t. for 1½ mile, is equal to the traction of the whole load to a mile.

Then for trains that receive no help at the passage of the

inclined planes, we must reckon the distance for which the draft has taken place, as equal to 34½ miles *on a level;* and for the engines that are helped on the acclivity; we must reckon the work they have done as equal to the traction of their load to a distance of 29½ miles *on a level.* The difference which exists in these two cases, is of $\frac{1}{8}$ in plus for the unassisted engines. This is the work done by the helping engines when they are employed, and the surplus of work produced by the passage of the planes.

It is from those distances of 29.5 miles and 34.5 miles, that the numbers placed in the eighth column of the preceding table have been deduced in each experiment.

In examining the results contained in that table, we find that they agree with the rule deduced above from the theory of the engine.

For the ATLAS, the average of the experiments made with 25 wagons, gives 119 t. conveyed by 1136 lbs. of coke. Calculating upon this data, and adding $\frac{1}{8}$ for the cases where there has been no help, we find

	tons.	lbs.	Calculation.	Experiment.
ATLAS	119 and tender	1136.		
	190 and tender	- - -	1531 - - -	1596
	95 and tender	- - -	1002 - - -	1081
	65 and tender	- - -	835 - - -	1012
	35 and tender	- - -	779 - - -	881
	25 and tender	- - -	719 - - -	720
VESTA	93 and tender	916.		
	34 and tender	- - -	668 - - -	774
VULCAN	98 and tender	1071.		
	34 and tender	- - -	773 - - -	664
LEEDS	83 and tender	897.		
	32 and tender	- - -	697 - - -	690
FURY	51 and tender	806.		
	44 and tender	- - -	759 - - -	746

If we take into account the accessory circumstances, we

shall find between the calculation and the experiment, as complete a coincidence as the nature of the experiments themselves could allow; for, besides the above-mentioned circumstances, the greasing of the carriages, the quality of the coke, and, above all, the manner in which the fire-place is filled after the experiment, are subject to produce considerable differences, notwithstanding the most scrupulous attention.

The experiments we have related, give the quantity of coke consumed during the trip.

It is however clear, that in the interval between one trip and another, the engine, although at rest, continues to consume a certain quantity of fuel, because its fire must be kept up for the following journey. It is true that several of those engines, such as the Atlas, Vesta, and some others, have a particular sort of apparatus, by means of which, while the engine is at rest, the steam that continues to be generated in the boiler may be led to the tender. That steam is then not completely lost, being condensed in the boiler, and serving to heat the water it contains. But all the engines are not disposed in that manner.

Besides there is in all cases consumed, every morning, a certain quantity of fuel for heating all the parts of the engine and the water of the boiler.

A surplus of consumption must therefore be calculated for those two objects. This is a practical piece of information which will find its place hereafter.

The researches contained in the work, give the solution of all such questions as are most important for the application of locomotive engines to the draft of loads on railways. They give the means of measuring the pressure of the steam; of calculating the load, the velocity, and the proportions of the engines; of valuing the different sorts of resistance they have to overcome; of taking into account the influence of additional circumstances on their motion; and, finally, of knowing their consumption of fuel.

Here naturally our work terminates. However, as a knowledge of these engines cannot be complete, unless we are able to calculate also the expenses they will require for a given draft, we add in an Appendix the necessary information, by means of which that important point may be established.

APPENDIX.

EXPENSES OF HAULAGE BY LOCOMOTIVE ENGINES ON RAILWAYS.

We have said that, in order to complete the knowledge of locomotive engines, we have still to consider them as a matter of speculation; that is to say, to examine the amount of the expenses attending the haulage by means of locomotive engines on railways. That research is the object of the present Appendix.

We shall draw the documents we have to present on that subject from the two most flourishing undertakings of the kind in England: the Liverpool and Darlington Railways. They will have, besides, the advantage of presenting examples of two very different sorts of conveyance: the one very rapid, and principally composed of passengers; the other slow, and composed of goods.

The expenses attending more especially the haulage by means of locomotive engines, are limited to the keeping in repair of the engines, the maintenance of the way, and the consumption of fuel. There are some other expenses, also, but they do not give occasion to discussion, and it will be sufficient to find their amount stated in the specified reports we subjoin at the end of this Appendix.

SECTION 1.—*Expense for repairs of Locomotive Engines.*

In the outlays above enumerated, the expenses which must naturally first of all draw our attention, are those which attend the keeping in repair of the engines.

Before we enter into any calculations on that head, it is necessary to mention that what is meant by repairs to the engines, is nothing less than their complete reconstruction;

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that is to say, that when an engine requires any repair, unless it be for some trifling accident, it is taken to pieces and a new one is constructed, which receives the same name as the first, and in the construction of which are made to serve all such parts of the old engine as are still capable of being used with advantage. The consequence of this is, that a reconstructed or repaired engine is literally a new one. The repairs amount thus to considerable sums, but they include also the renewal of the engines.

According to the tables at the end of this work, it will be seen that in the year ending on the 30th of June, 1834, the repairs of the engines of the Liverpool Railway cost:

From June 30, to December 31, 1833.

Materials for repairs	£3,755 3 7	
Workmen	4,401 4 10	
Repairs out of the establishment	613 3 9	
		£8,769 12 2

From December 31, 1833, to June 30, 1834.

Materials	£4,140 19 6	
Workmen	5,432 8 8	
		9,573 8 2
		£18,343 0 4

The question is now what was the work executed by those engines during that interval? By consulting the specified statements which will be found below, we see that the goods conveyed on the line during the year have been:

Between Liverpool and Manchester (30 miles)	139,328 t.
On part of the line, making an average of 15 miles,* 24,934 t., which, on the whole, is equal to	12,467
Sum	151,795 t.

In the tables we mentioned, we find some other haulage executed, such as that for Bolton and that of coals; but this work is executed by engines which do not belong to the company, and for that reason we do not take it into account in this place.

The above-mentioned weight is that of the goods conveyed, to which must be added the weight of the wagons. Now, on that railway, the average load of a wagon is 3.5 t., and the wagon itself weighs 1.5 t.; so the weight of the carriages that

* The distance to which the company carries the Wigan and Warrington trade, which makes the principal part of this article, is 15 miles.

served for the above-mentioned tonnage will be known by multiplying the number obtained, by the ratio $\frac{1.5}{3.5}$. And as, moreover, the engines, for want of sufficient returning traffic, are obliged to bring back half the wagons empty in one of the two directions, or ¼ of the whole, we shall have for the *gross weight* drawn by the engines in the course of the year—

Weight of the goods	151,795 t.
Weight of the corresponding wagons	65,055
Weight of the wagons brought back empty	16,264
	233,114 t.

This is the tonnage of the goods, to which must be added that of the travellers. In the course of the year, 415,747 travellers were conveyed from one city to the other in 6570 journeys.* This makes an average of 64 travellers per train. The coaches required for that number of travellers, including the empty carriages added to each train to be ready for any emergency, are six carriages of the first class, or five of the second.†

The weight of six first class coaches, including the mail, is	21 t.
The weight of a second class train of five carriages, including one glass coach, is	12.6

Lastly, for 13 trains of the first class there are 16 of the second. Thus, the average weight of the carriages for every 64 travellers may be reckoned at 16.4 t.

Consequently, the total weight corresponding to the travellers conveyed was:

415,747 travellers at 15 per t.	27,717 t.
Corresponding weight of the carriages	107,748
Luggage of the travellers, at 28 lbs. each	5,197
	140,662 t.

Thus the total definite weight, drawn by the engines belonging to the company, during the year was—

* This is the number of the travellers inscribed on the company's books. It includes neither the travellers put down nor those taken up on the road, the numbers of which balance each other.

† The first class carriages are glass coaches, containing each 18 persons; they weigh 3.65 t. Those of the second class are open, and have 24 places; their weight is 2.23 t. Lastly, the mail coaches weigh 2.71 t., and carry 10 travellers. Each glass coach has besides one outside place.

Gross weight for goods	233,114 t.
Gross weight for travellers	140,662
	373,776 t.

We have already shown in this work (Chap. IX. § 2) that, taking into account the surplus of resistance occasioned by the gravity at the passage of the inclined planes of that line, the load must be considered as carried to a distance of 34 miles and a half on a level. Thus, as a ton carried to a distance of 34.5 miles is equal to 34.5 t. carried to a distance of one mile, the draft here above is equal to 12,895,272 gross tons carried to one mile on a level.

For that haulage the repairs of the engines cost £18,343 0s. 4., consequently the repairs, per gross ton carried to one mile on a level amounted to

0.342*d.*

In order to execute this haulage, the engines made 6570 journeys drawing stage-coaches, that is to say, with a velocity of 20 miles an hour; and 5086 journeys, with goods, or with a velocity of 12.5 miles an hour. The average velocity of the haulage, was consequently in miles per hour, 16.73 miles.

We have said elsewhere that the Liverpool and Manchester Railway Company possesses at present thirty locomotive engines. It must not be concluded, however, that that number is necessary in order to execute the above said haulage. Of these 30 engines about one-third are useless. They are the most ancient which, having been constructed at the first establishment of the railway, at a time when the company had not yet obtained sufficient experience in that respect, are found now to be out of proportion with the work required of them.

The engines actually in daily activity on the road amount to about 10 or 11, and with an equal number in repair or in reserve the business might completely be ensured. This is in fact what happens at present, the surplus, above that number, being nearly abandoned.

We shall complete what we have just been saying on the Liverpool locomotive engines, by adding a document that will show what these engines are capable of executing in a daily work, and the improvement they have undergone in the course of the last few years, in respect to the solidity of their construction.

WORK DONE BY THE TEN BEST ENGINES OF THE LIVERPOOL AND MANCHESTER RAILWAY, DURING THE YEARS 1831, 1832, 1833, AND THE FIRST TWELVE WEEKS OF 1834.

Year.	Name of the Engine.	Total distance travelled by the engine.	Total time the engine has been on the road, either in activity, or in repair.
		miles.	weeks.
1831.	Mercury	22,212	52
	Jupiter	22,528	44
	Planet	20,404	52
	Saturn	19,510	38
	Mars	18,645	50
	Majestic	18,253	52
	North Star	15,677	52
	Northumbrian	15,607	52
	Phœnix	15,405	52
	Sun	13,434	37
	Sum	182,675	481
	Average per week	380	
1832.	Vulcan	26,053	52
	Liver	22,651	43
	Venus	20,464	52
	Etna	20,399	52
	Saturn	20,312	52
	Vesta	17,739	52
	Victory	17,082	52
	Planet	16,885	52
	Sun	16,535	52
	Fury	15,603	52
	Sum	193,723	511
	Average per week	379	

WORK DONE BY THE TEN BEST ENGINES OF THE LIVERPOOL AND MANCHESTER RAILWAY, DURING THE YEARS 1831, 1832, 1833, AND THE FIRST TWELVE WEEKS OF 1834.

Year.	Name of the Engine.	Total distance travelled by the engine.	Total time the engine has been on the road, either in activity or in repair.
		miles.	weeks.
1833.	Jupiter	31,582	52
	Ajax	26,163	52
	Firefly	24,879	39
	Liver	23,134	52
	Pluto	20,308	52
	Vesta	19,838	52
	Leeds	19,364	48
	Saturn	18,738	52
	Venus	18,348	52
	Etna	17,763	52
	Sum	220,117	503
	Average per week	438	
1834.	Firefly	8,542	12
	Vulcan	8,526	12
	Saturn	7,290	12
	Liver	7,080	12
	Sun	7,080	12
	Etna	6,557	12
	Leeds	5,712	12
	Ajax	4,890	12
	Venus	4,632	12
	Pluto	4,246	12
	Sum	64,555	120
	Average per week	538	

Among those engines, the *Liver* had worked for 107 weeks, had travelled 52,865 miles, or, on an average, 494 miles a-week during all that time; the *Firefly* had worked 57 weeks, had travelled a distance of 33,421 miles, or 586 miles a-week, and neither of these engines at the period in question, had yet required a fundamental repair.*

This statement shows what can be expected from locomotive engines, when constructed with care and of good materials; and there is no doubt that, in time, more work will still be obtained from them.

In order to give also an instance of the expense of repairs of locomotive engines, under other circumstances, and with another mode of construction of the engines, we shall set down here the work performed by the locomotive engines on the Darlington Railway, during the same year, that is to say, from June 30, 1833, to June 30, 1834, and the amount of expenses for repairing those engines for the same space of time.

On this railway the number of trips of 20 miles, down hill, performed in the course of the year, was 5318½. In each of these journeys the engine had to draw, in coals, a load of 63.6 t., which puts the total work at

6,764,951 t. carried to the distance of one mile.

But as this tonnage does not include the tare of the wagons, and as, independently of this descending trade, it is also necessary to bring the empty wagons *up* the line again, this point requires our entering into some particulars, in order to be able to deduce from it the work really executed by the engines.

We shall elucidate it before we go any farther.

When a weight of one ton is drawn on a level railway, we have seen that it requires a traction of 8 lbs. But if the line is not all on a level, upon each *ascending* plane, the gra-

* The greater part of these excellent engines were built by Mr. R. Stephenson, the son of Mr. R. Stephenson, so well known for his important and numerous improvements in this branch of industry.

The *Liver* engine, the merit of which is sufficiently established by the above stated facts, is the work of Messrs. Edward Bury and Kennedie, of Liverpool.

vity of the mass drawn will be an additional resistance to be overcome, and must consequently be added to the 8 lbs. traction, already necessary in order to overcome the friction of the wagons. For the contrary reason, in the *descending* planes that gravity enters into deduction of the power to be exerted, and must consequently be subtracted instead of added.

If, however, the same train, after having ascended an inclined plane, descends another equal one, the addition in one case being exactly equal to the subtraction in the other, the consequence will be, that the definitive resistance of a ton will remain the same as if the way had been level.

Or, if the way has a known average inclination, from which it deviates, at times augmenting and at others diminishing, returning, however, always to that average inclination, the same principle of compensation will stand good still, and it will be sufficient to calculate the traction required on that average inclination.

But this principle, which has its foundation in the supposition that the engine is just as much eased in one point as it is overcharged in another, ceases to be true on all such planes where the gravity surpasses the friction; that is to say, on all planes where the inclination is greater than $\frac{1}{280}$. In fact, beyond that point the overcharge in ascending continues to augment rapidly, while the load is going down, already reduced to nothing on a plane at $\frac{1}{280}$, cannot diminish any more. All compensation therefore ceases.

This remark proves that the consideration of the gravity, on the average inclination of a line, gives the real resistance on that line, only in case it contains no *descending* planes of a greater inclination than $\frac{1}{280}$, or in case those that are in that predicament have been reckoned separately.

Applying that principle to the Darlington Railway we find, according to the section of that line,* that on its total

* The part of that railway travelled by the Locomotive engines begins at the foot of Brusselton inclined plane, at an elevation of 383 ft. 1 in. above the quay at Stockton, where it terminates, after passing over the following inclinations:—

Miles.			
0.46	- - -	descent - - -	at $\frac{1}{311}$
0.06	- - -	do - - -	$\frac{1}{325}$
0.92	- - -	do - - -	$\frac{1}{144}$
1.45	- - -	do - - -	$\frac{1}{121}$

length there are eight inclined planes on which the gravity surpasses the friction. The length of these eight planes being together 10.23 miles, which is a half of the whole distance, we see that, during one half of their journey in descending, the Darlington engines have no traction to exercise and that the trains go down of themselves. The remaining half of the way, being practically level ($22\frac{1}{2}$ feet in descent for $10\frac{1}{2}$ miles,) the engines have on that part of the traction of a level line, that is to say, 8 lbs. per ton. So their average traction during the whole descent is 4 lbs. per ton, or, in other words, their work is equal to the draft of their load to half the distance on a level. We see here how great a mistake we would have made if we had taken as a rule the *average* inclination of the whole line; for that inclination being $\frac{1}{286}$, we would naturally have concluded that for all the descending trade, the traction was almost reduced to nothing.

Coming back, therefore, to the tonnage on the line, we have seen that it amounts, for the *goods*, to

---

Miles.		
2.25	descent	at $\frac{1}{528}$
1.25	do	$\frac{1}{135}$
1.01	do	$\frac{1}{832}$
1.76	do	$\frac{1}{136}$
0.20	do	$\frac{1}{396}$
1.75	do	$\frac{1}{1584}$
1.61	do	$\frac{1}{1468}$
1.64	do	$\frac{1}{204}$
0.23	do	$\frac{1}{713}$
2.09	do	$\frac{1}{2192}$
1.25	do	$\frac{1}{253}$
0.03	level	
0.81	descent	$\frac{1}{286}$
0.05	do	$\frac{1}{487}$
0.80	do	$\frac{1}{1584}$
1.16	do	$\frac{1}{104}$

Sum - 20.78. Average inclination, 383 feet on 109,692 feet or $\frac{1}{286}$.

Besides the principal line, there are lateral branches over which the locomotive engines also travel, but the level of which has not been taken. The aggregate space travelled over by the locomotive engines is 24 miles. The rest of the railway, consisting of 16 miles, is worked by horses and by stationary steam-engines.

6,764,951 t.

This number does not include the weight of the wagons themselves. These wagons weighing 1.30 t., and their load being 2.65 t., the addition to be made on that account, will be found in multiplying the above number by the ratio $\frac{1.30}{2.65}$. Thus the total weight carried in *going down* the line is

Weight of the coals - - - -	6,764,951 t.
Weight of the wagon - - - -	3,318,656 t.
Total wt. drawn to a distance of one mile descending	10,083,607 gr. tons.

We have seen that the draft of one ton to the distance of one mile, in going down the line, is equal to the draft of the same load to the distance of half-a-mile *on a level.* The above-mentioned tonnage referred to a level, represents consequently

5,041,803 gross tons carried to a distance of a mile.

In order to estimate the draft in *going up,* we may retain or not the division of the line in two parts, the result is the same; but the simplest way is to make use of the average inclination at $\frac{1}{318}$. The calculation we have to make regarding only the *ascending* line, which contains no descending plane, and, *a fortiori,* no descending plane of a greater inclination than $\frac{1}{210}$, the division established above is no longer necessary.

Considering, then, that the ascending trains are composed of 24 empty wagons, weighing together 31.2 t.; that, besides, on the inclined planes, the gravity of the engine and its tenders offers an additional resistance which would not take place on a level; finally, that the weight of the engine is 10 to 11 t., and that of the two tenders, half empty, 4.5 t.; which makes in all, on the inclined plane, a mass of 46.2 t., to be moved; it will be seen that the total resistance opposed by the train is,

Friction of the wagons, 31.2 t. at 8 lbs. per ton - -	249.6 lbs.
Gravity of the mass 46.2 t. on an inclined plane at $\frac{1}{318}$	362
Total resistance -	611.6 lbs.

This, being the resistance that results from a train composed of 31.2 t., makes per ton, 19.60 lbs., or, in round numbers, 20 lbs. As we know, on the other hand, that on a level one ton requires only 8 lbs. traction, we see that the necessary force is here twice and a-half as great; or, in other words, we see that the draft of one ton to a distance of one mile, *going up* that line, is equal to that of the same load to 2.5 miles *on a level.*

This granted, we have found that the haulage of the wagons is equal to 3,318,656 tons conveyed to the distance of one mile in going up. Referring this to a level, it will be represented by the same number multiplied by 2.5, that is to say it will be

8,296,640 gr. t. carried to a distance of one mile on a level.

From which follows, finally, that the total work executed by these engines and referred to a level, is

Draft in going down, in gross tons carried to a distance of one mile on a level - - - - - - -	5,041,803 t.
Draft in going up, measured in the same way - -	8,296,640
Sum - -	13,338,443 t.

The number of tons of coals which produced this draft being, as we have seen, 6,764,951 t., we find that, on account of the weight of the necessary wagons and the difficulty of the draft in going up, the haulage of those six millions and a-half of *goods* produced really a draft equal to thirteen millions of tons on a level; that is to say, to be more accurate, that in comparing these two numbers, we see that the real work executed by the engines may be deduced from the weight of the goods by multiplying the latter number by 1.9718.

This first point established, we may now come to the amount of the expenses of repairs.

After having for a long while kept and repaired their engines themselves, the Directors of the Darlington Company decided, in order to avoid minute accounts, to enter into a contract for that; and, in consequence, in 1833, they put their engines in the hands of three persons.

By the contract entered into, and which is at present in force, the company pays $\frac{4}{10}$ of a penny per ton of *goods,* carried to a distance of one mile; and, for that price, the

contractors have undertaken, not only to keep the engines in good repair, furnishing workmen and materials, but also to pay all the current expenses of haulage, such as salary of the engine men, fuel, oil, grease, &c. Besides this, they must also pay the company an interest of five per cent. on the capital representing the value of the engines, and of all the establishments placed at their disposal for working.

The total sum paid to the contractors by the company for that object during the year ending June 30, 1834, was

£ 11,347 1*s.* 9*d.*

And deducting the expenses for rent, interest of capital and haulage, the amount of which is known, the directors of the company reckon that the definitive sum remaining with the contractors for the repairs of the engines (bars of fire-box included,) amount, with the general profit on the whole undertaking, to

£ 5,732 18*s.* 5*d.*

This sum has been expended for the carriage of 13,338,443 gross tons to a distance of one mile on a level; so that finally the expense, per gross ton carried to one mile on a level, including the profits on the undertaking, amount to

0.103*d.*

As a complement to what we have said, and to show on this railway as well as upon the Liverpool one, the work the engines are able to perform, we shall give a table of the haulage executed, and repairs undergone by the engines during the five last months of the year 1833.

STATEMENT OF THE WORK DONE BY THE LOCOMOTIVE ENGINES ON THE DARLINGTON RAILWAY, FROM JULY 1 TO DECEMBER 1, 1839.

Number of the engine.	Name of the engine.	Total number of miles travelled by the engine.	Tons of coals carried to one mile going down by the engine.	Gross tons carried to one mile on a level including the wagons and return.	Number of days that the engine was in activity.	Number of days that the engine was in repair.	Amount of the repairs made to the engine during that time. £	s.	d.	Amount of the repairs per gross ton carried to one mile on a level.	Observations.
		miles.	tons.	tons.	days.	days.	£	s.	d.	d.	
1	Locomotion	5,300	146,011	287,896	80	52	41	19	7	0.035	Boiler with a flue and two returning tubes.
2	Hope	3,100	82,305	162,281	63	69	57	5	5	0.085	with a single flue.
3	Black Diamond	1,000	26,920	53,078	27	105	14	0	5	0.063	with a single flue.
4	Diligence	80	1,906	3,758	2	130	13	18	3	0.889	Engine taken to pieces.
5	Royal George	700	23,733	46,794	11	121	161	7	8	0.828	Boiler with a flue and one returning tube.
6	Experiment	4,400	122,442	241.420	70	62	53	1	2	0.053	ditto.
7	Rocket	3,940	109,512	215,925	64	68	57	0	9	0.063	ditto.
8	Victory	10,600	349,150	688,418	107	25	58	3	10	0.020	ditto.
9	Globe	3,120	70,683	139,365	60	72	36	4	6	0.062	Boiler with 120 returning tubes.
10	Planet	1,200	20,429	40,280	27	105	53	7	5	0.318	with 88 "
11	North Star	2,400	47,546	93,746	55	77	32	5	10	0.083	with 88 "
12	Majestic	2,880	90,422	178,282	47	85	131	2	3	0.177	with 104 "
13	Coronation	2,940	97,687	192,609	52	80	46	16	2	0.058	with 104 "
14	William IV.	4,060	134,440	265,074	55	77	78	19	8	0.072	with 104 "
15	Northumbrian	4,480	143,885	283,698	59	73	67	14	11	0.057	with 104 "
16	Director	5,860	202,492	399,253	91	41	107	19	11	0.065	Boiler with tubes on the model of Napier's patent.
17	Lord Brougham	4,780	155,729	307,051	62	70	62	5	10	0.049	Boiler with 104 returning tubes.
18	Shildon	4,720	159,400	314,289	63	22	49	16	3	0.038	with a flue and two returning tubes.
19	Darlington	6,180	200,110	394,559	88	44	45	0	6	0.027	with a flue and two returning tubes.
20	Adelaide	3,700	126,390	249,202	71	61	90	11	7	0.087	with 104 returning tubes.
21	Earl Grey	7,960	276,462	545,098	110	22	14	19	6	0.007	with a flue and two returning tubes.
22	Lord Durham	6,480	213,737	421,424	84	48	67	13	8	0.039	with 104 returning tubes.
23	Wilberforce	4,200	141,534	279,062	55	9	51	17	11	0.045	with 104 "
	Sums	94,080	2,942,925	5,802,562	1403	1518	1393	13	0	0.058	

The greatest part of the machines were constructed by Mr. Timothy Hackworth, of Shildon near Darlington, and bear testimony to his skill. Twelve of them were almost new at the time this statement was made.

Section 2.—*Expense for Maintenance of Way.*

The expenses for keeping the Liverpool Railway in repair, during the year we are considering, are given in the reports that will be found below. From the sums put down must be deducted the articles *ballast* and *new rails*, the first being caused by the recent construction of the road, that is to say, by the gradual sinking of the embankments, which are not completely compact, and the second being an extraordinary replacing of the rails on a part of the line.

Putting, therefore, these two articles aside, the expense of repairing the railway, during the year ending on the 1st of June, 1834, were

£ 11,053 2s. 6d.

During the same time, the loads that passed on the railway drawn either by the company's engines, or by engines belonging to other companies, were

Goods on the whole road . . .	139,328 t.	
—— on the half of the road 24,934 t., making on the whole line . . .	12,467	
—— between Bolton and Manchester or Liverpool 38,341 t., or on the whole road .	19,170	
Coals on the half of the line 86,173, or on the whole	43,086	
		214,051 t.
Corresponding wagons ($\frac{1.5}{3.5}$ of the weight of the goods) .		128,431
Wagons brought back empty (1·4 of the whole) . .		32,108
Carriages, and passengers' luggage, as above . . .		140,662
Sum		515,252 t.

Thus 515,252 gr. t. passed on each mile of the railway, not including the weight of the engines and their tender.

The expenses for the 30 miles, length of the railway, having amounted to £11,053 2s. 6d., or to £368 8s. 1d. per mile, the expense per mile for each ton carried was

0.171*d.*

In this calculation we have only taken the *useful* length of the railway; that is to say, that we have omitted the sidings &c., they being only the necessary complement of the principal line.

On the Darlington line, during the same year, the expenses for repairs on the 24 miles, run over by the locomotive engines were

Workmen - - - - - -	L4,253 0 0
Materials - - - - - -	2,060 0 0
	L6,313 0 0*

The weight that passed during the same time, on that part of the railway, was:

Coals, 6,764,951 tons carried to a distance of one mile, or upon the whole of the 24 miles - - - -	281,873 t.
Corresponding wagons($\frac{1.30}{2.65}$ of the weight of the goods) -	138,277
Wagons going up the line (same weight) - - - -	138,277
	558,427 t.†

The expenses for the whole of these 24 miles amounting to £6313, we have for each mile £263 0s. 10d. Thus the expenses for maintenance of way, per mile, and for each gross ton conveyed on the road, were

0.113 d.

We have here also, as well as above, left out the crossings, sidings, &c.

This amount, would undoubtedly be diminished if the

* The total expense for repairs of the line during the year we are considering were

Workmen - -	For the 24 miles run over by the locomotive engines -	L4,253	0	0
	Nor the 16 miles worked by horses or stationary engines -	1,067	5	0
Materials for repairs	Space run over by the locomotive engines - - -	2,060	0	0
	Part worked by horses or stationary engines - -	518	3	8
Repairs to bridges - - - - -		69	17	7
Repairs to walls and fences - - - -		280	7	11
Accidental expenses - - - - -		467	3	7
	Total expenses	L8,715	17	9

N.B. The distinction between the expenses relating to the spaces run over by locomotive engines and by horses, could only be made by approximation; as the company does not keep separate accounts in that respect.

† Besides this weight, there passes on the line a small number of stage coaches, which for the last few months have been drawn by the locomotive engines. But this haulage being inconsiderable, we did not wish to embarrass our calculation with it.

Darlington wagons were on springs, like those of the Liverpool Railway.

These expenses, as we have seen, amount only to the two-thirds of those of the Liverpool Railway for the same object. The difference is owing to the rapid motion of the engines and carriages that pass on the latter railway. But is chiefly in the expense for repairs of engines that this effect of velocity is felt.

It must not, however, be supposed that the considerable difference observed in that respect, between the engines of the two companies, is exclusively owing to the velocity of the motion. That velocity enters, indeed, for a great part in it, but the conditions attending each sort of business have a no less considerable influence on it. What we mean is, that passengers forming the chief business on the Liverpool line, their safety requires that a much greater care be taken of the engines than when the load is composed only of coals, as on the Darlington Railway. The consequence is, that the Liverpool engines are kept with a decree of care, we might even say of luxury, to which the Darlington ones can by no means be compared. In order to explain completely our idea, we shall say that the business of the Darlington Railway is a business of wagonage, and that of the Liverpool Railway a business of stage coaches.

The *data* laid down above must therefore be taken each in their specialty, that is to say, the one as suitable to a slow motion, with engines of a certain construction and intended for the draft of goods, and the other to a rapid motion with engines of a different construction, and intended for the draft of passengers.

Before we close this article, we must remark that the repairs of the railway consist principally in replacing the blocks, chairs, keys, and pins. The rails themselves, being in malleable iron, seldom break. As for their gradual decrease of weight, by wear, this is a very inconsiderable effect.

On May 10th, 1831, on the Liverpool line, a malleable iron rail, 15 feet long, carefully cleaned, weighed 177 lbs. 10½ oz. On February the 10th, 1833, the same rail, taken up by Mr. J. Locke, then resident engineer on the line, and well cleaned as before, weighed 176 lbs. 8 oz. It had consequently lost in 21 months a weight of 18½ oz. The number of gross tons that had passed on the rail during that

time was estimated at 600,000. Thus we see that with so considerable a tonnage, and with the velocity of the motion on that railway, the annual loss of the rail was only $\frac{1}{268}$ of its primitive weight. So that it would require more than a hundred years to reduce it to the half of its present strength.

SECTION 3.—*Expense of Fuel.*

In regard to fuel, we have already, in Chapter IX. of this work, related experiments from which may be deduced the consumption of fuel according to the load the engines have to draw.

However, as in the intervals of the trips the fire must be kept up, and as, besides, there are always unavoidable losses during working, an increase of expense in that respect must naturally be expected in practice. This we also learn in a positive manner by the examination of facts.

According to the half-yearly reports of the Liverpool Railway Company, for the year ending June 30, 1834, the expense for fuel for the locomotive engines was

£6,079 15s. 8d.

The number of trips performed was 11,656; consequently the expense for fuel for each journey amounted to 10.432s., and as the average price of coke employed during that year on the railway was 23.5s., the consumption of fuel, measured in weight, amounted to 994.37 lbs. per trip.

We have seen (Appendix, § 1.) that the total number of gross tons conveyed by the locomotive engines of the company from one end of the Railway to the other, in the same number of journeys was

373,776 t.

The average load of the engines was consequently about 32 tons.

A load of 32 tons, not including the tender, has consequently required, by the fact, a consumption of coke of 994 lbs. So, considering that the load has been really carried to a distance of 34½ miles, this makes 0.90 lbs. per gross ton drawn to a distance of one mile on a level. Our special Experiments (Chap. IX. § 2) only give an average con-

sumption of 784 lbs. of coke for a load of 32 t. By this it will be seen that, in practice, and, with the nature of the business on that line, the different losses amount to one-fourth of the expense of the active work.

This increase is owing not only to the necessary expense for lighting the fire every morning, but also to the necessity, on that line, of keeping, for the passage of the inclined planes, helping engines, the fire of which must remain lit the whole day, although they only serve at distant intervals, and to the long delays between one journey and another. These circumstances, that of the helping engines alone excepted, are inevitable in a business of the nature of that of Liverpool.

On the Darlington Railway the same causes of loss do not exist, at least not to the same degree.

According to the notes, carefully kept by the directors of that company to serve as a foundation to the contracts they sign, the quantity of coals consumed on an average, during one journey of an engine, that is to say, to convey 24 wagons to a distance of 20 miles down hill, and bring them back again empty to the same distance up hill, costs the enginemen 4s. 9¾d., when the coals are at 5s. per ton. So the weight of coals consumed is 2157 lbs.

The *useful* load drawn by the engine is composed of 63,60 t. of coals in going down, and there is no *useful* load at all in going up; making an average of 31.80 tons of goods drawn to a distance of 40 miles in all.

This weight, from what we have seen (Appendix, § 1.,) corresponds with a *gross* weight, drawn on a level to the same distance, of

$$31.80 \text{ t.} \times 1.9717 = 62.70 \text{ t.};$$

the consumption of coals per gross ton carried to a distance of one mile on a level is, consequently, 0.86 lb.

This is nearly the same consumption as on the Liverpool Railway, especially if we consider that a ton of coals of a good quality, produces a little more evaporation than the same weight of good coke.*

This result may appear surprising, the boilers of the Darlington engines being generally constructed on a less

* The proportion of the quantity of coke prepared in a closed vessel, and of Newcastle coals, necessary to transform the same quantity of water into steam at the same pressure, is nearly as 14 to 13,

economical principle, as to the application of heat, than the Liverpool ones; but considering the way of working on each line, this circumstance will easily be accounted for. On the Darlington Railway the engines never go off but with a full load; that is to say, that they draw, as we have mentioned, an average weight of 62.7 t. per trip, and we know that this circumstance is favourable to the consumption of fuel. If these engines were to draw only an average load of 32 t., like the Liverpool ones, their comparative consumption would certainly be greater. To this must also be added that, on the Darlington Railway, the engines undergo no delay between their journeys, and that the invariability in the load and in the speed makes it unnecessary to give them more evaporating power than is strictly wanted for their motion. The consequence is that one never sees at the valve that enormous blowing which takes away from the Liverpool locomotive engines a fourth part of their produce.

It is to these combined circumstances that the practical result appearing in this case, must be attributed.

Section 4.—*Total Expense of Haulage.*

The remaining expenses of the haulage require, on our part, no separate discussion. The particulars will be found in the following statements relating to the Liverpool Company. But their aggregate amount acquaints us with the total expense of haulage by means of locomotive engines, and this is a point which requires some consideration as well as the former ones.

According to the statements concerning the year in question, we see that the total expenses of the Liverpool Company amounted to the following sums:

	£	s.	d.
1st half-year	56,350	1	9
2d half-year	60,092	15	11
	£116,442	17	8

But our purpose being to know the expenses relating to the use of the locomotive engines taken separately, in order to compare the amount with the total haulage they executed, we must deduct from that sum the following articles:

		£	s.	d.
1st. Interest on loans . . .	1st half-year	5,140	6	4
	2d half-year	5,546	4	0
2d. Stationary engine and tunnel disbursements . . .	1st half-year	1,307	16	6
	2d half-year	986	10	2
3d. New rails, this being an extraordinary expense	1st half-year	150	16	3
	2d half-year	3,153	14	5
4th. From the amount for maintenance of way, new rails not included, must be deducted 1-10th for expenses concerning the tunnels, that are not worked by the locomotive engines and the length of which is 1½ mile on the 31 miles of the whole line	1st half-year	627	10	0
	2d half-year	619	14	0
5th. On the rest of the expense for maintenance of way must also be deducted 2-5ths, being expenses occasioned by the passage, with their trains, of locomotive engines not belonging to the company. The haulage effected by the engines of the company being 373,776 tons, carried on the whole line. We have seen (Appendix, § 2) that the work of the engines not belonging to the company, raises the tonnage to 515,252 tons; consequently the work of the latter engines is 141,476 tons, or 2-5ths of the haulage of the company's engines. This article makes .	1st half-year	2,258	18	0
	2d half-year	2,231	0	0
Total sum to be deducted .		£22,022	9	0
Remains for expenses concerning the work of the company's locomotive engines .		94,420	8	0

The haulage executed by the same engines being

12,895,272 gross tons carried to a distance of one mile:

the consequence is that, on the Liverpool Railway, at an average velocity of 16.73 miles per hour, the total expense of haulage by locomotive engines amounts to

175 d. *per gross ton carried to a distance of one mile on a level.*

This includes all sorts of expenses, carriages, rent, offices, &c.

On the Darlington Railway the expenses of haulage are much lower. The company estimates them at 1.00d. *per ton of coals* carried to one mile *in going down* the line; which, after our calculation (Appendix, § 1.,) would make 0.51d. per *gross* ton carried to one mile *on a level.*

The cause of that difference between the two railways has already been mentioned, being the velocity of the motion and the nature of the goods conveyed. To this must also be

added the considerable difference in the price of fuel, the Darlington Company employing coals which cost only 5s. per ton, instead of 23s. 6d., the price of the coke used by the Liverpool company. But the use on that line of several ways of working either by locomotive or stationary engines, or by horses, does not permit us to class and verify the expenses with the same precision as in the case of Liverpool. This is the reason why we shall not enter into any particulars in that respect.

Section 5.—*Profits.*

After having examined the expenses, it is also necessary to cast a look on the receipts. Before we go over to the specified statements of the expenses of all sorts of the Liverpool Company, we shall therefore take down here, from those same statements, the amount of the profits made by the company from the opening of the railway. This sketch will show that, if the mode of haulage in question necessitates considerable expenses for its establishment, the profits it produces are fully adequate to indemnify speedily the share-holders.

The road was opened to trade on September 16th, 1830, and from that period the dividends per share of £100 sterling amounted to the following sums:

December 31, 1830 - - - - - -	£2 0 0
June 30, 1831 - - - - - - -	4 10 0
December 31, 1831 - - - - - -	4 17 8
June 30, 1832 - - - - - -	4 4 8
December 31, 1832 - - - - - -	4 8 0
June 30, 1833 - - - - - - -	4 7 6
December 31, 1833 (besides a reserved fund of 4,088 8 s. 10d.) - - - - - - -	4 15 3
June 30, 1834 - - - - - -	4 15 2
Total sum from Sep. 16, 1830, to June 30, 1834, that is to say, in three years, nine months and a-half - .	£33 18 3

This sum makes 9 per cent. a-year, besides the reserved fund laid aside by the company, and notwithstanding the extraordinary expenses inevitable at the beginning of an undertaking, which being the first of its kind, was necessarily obliged to pay dearly for its own experience, whilst future railways will profit by that acquired by their predecessors.

Besides this high interest for the capital invested, we repeat that the shares of this railway, from the original price of £100 sterling, have risen, and sell at present, after four years establishment only, at £210; and that those of the Darlington Railroad, which boasts only nine years existence, give 8 per cent. interest, and have risen in that short interval from £100 to £300, which is their present price.

This plain recital of facts speaks volumes. It is, therefore, unnecessary for us to add any reflections.

We shall be happy if the elucidations we have already given and those we intend to subjoin be of use to persons who may feel inclined to engage in these speculations, which, in regard to expenses, cannot fail to be as advantageous to their private fortune as to the prosperity of the country at large.

We shall conclude this Appendix by giving the specified statements of the receipts and expenditure of the Liverpool Company, from its origin to the present moment.

EXTRACTS

FROM THE

REPORTS OF THE DIRECTORS OF THE LIVERPOOL AND MANCHESTER RAILWAY.

FROM THE

Opening of the Railway, on the 16th September, 1830, *to the 30th June*, 1834.

STATEMENT OF EXPENDITURE ON CAPITAL ACCOUNT.

Amount of expenditure on the construction of the way and the works, from the commencement of the undertaking to 31st December, 1833 - - -	£1,089,818	17	7

ANNUAL OR WORKING ACCOUNT.

FROM 16TH SEPTEMBER TO 31ST DECEMBER, 1830.

Nett profits of the company - - - -	£14,432	19	5
Dividend per share of £100 - - - -	2	0	0

HALF-YEAR ENDING 30TH JUNE, 1831.

Nett profits of the company - - - -	30,314	9	10
Dividend per share of £100 - - - -	4	10	0

HALF-YEAR ENDING 31ST DECEMBER, 1831.

	Tons.
Merchandise between Liverpool and Manchester	52,224
Road traffic - - - - -	2,347
Between Liverpool and the Bolton junction -	10,917
Coal from Huyton, Eltonhead, and Haydock collieries brought by the Company's engines -	7,198
Coal from Hulton brought by the Bolton engines	1,198
Number of passengers booked at the Company's offices - - - -	256,321
Number of trips of 30 miles performed by the locomotive engines with passengers	2,944
Do. with goods - - - -	2,298
Do. with coals - - - -	150

Receipts.

Coach department	£58,348	10	0			
General merchandise	30,764	17	8			
Coal department	695	14	4			
				£89,809	2	0

Expenses.

Office establishment	902	3	10			
Coal disbursements	60	15	5			
Petty ditto	110	0	5			
Cart ditto	60	17	8			
Maintenance of way	6,599	12	6			
Charge for direction	297	19	0			
Coach office establishment	589	5	9			
Locomotive power	12,203	5	6			
Advertising	59	3	4			
Interest	2,737	7	3			
Rent	900	5	3			
Compensation (coaching department)	156	7	5			
Engineering department	625	0	0			
Carrying disbursements	10,450	12	3			
Taxes and rates	2,763	5	1			
Stationary engine disbursements	269	4	7			
Coach disbursements	6,709	7	11			
Wagon ditto	979	19	8			
Compensation (carrying department)	786	8	2			
Police establishment	1,490	14	1			
Law disbursements	98	9	10			
Bad debts	175	13	6			
				£49,025	18	5

Nett profit from 1st July to 31st Dec. 1831.	40,783	3	7
Dividend per share of £100	4	10	0
Nett profit on Sunday travelling per share of £100	0	7	8

HALF-YEAR ENDING 30TH JUNE, 1832.

		Tons.
Merchandise between Liverpool and Manchester		54,174
Traffic to and from different parts of the road		3,707
Between Liverpool and the Bolton junction		14,720
Coals from different parts of the road brought by the Company's engines		22,045
Coals brought by the Bolton engines		7,411
Number of passengers booked at the Company's offices	174,122	
Number of trips of 30 miles performed by locomotive engines with passengers	2,636	
Ditto with merchandise	2,248	
Ditto with coals	234	

Receipts.

Coaching department	40,044	14	7			
General Merchandise department	32,477	14	0			
Coal ditto	2,184	7	6			
				£74,706	16	1

Expenses.

		£	s.	d.
Bad debt account		£394	5	7
Coach disbursements.	Guards' and porters' wages £1104 4 6.—Parcel carts and drivers' wages, £254 10 5.—Omnibuses and duty, £1082 0 7.—Repairs and materials, £1777 9 4.—Gas, oil, tallow, &c. £228 14 6.—Stationary and sundry disbursements, £441 1 7	4888	0	11
Carrying disbursements.	Salaries, £1749 5 10—Porters' wages, £3862 0 8.—Brakesmen's wages, £461 5 9.—Oil, tallow, cordage, &c. £461 12 6.—Carting, £808 16 5—Repairs to jiggers, trucks, &c. £163 14 11.—Stationary and sundry expenses, £503 10 8.	8010	6	9
Coal ditto		26	8	10
Cartage (Manchester)		1420	4	9
Charge for direction		308	14	0
Compensation (coaching)		101	10	9
Compensation (carrying)		288	10	3
Coach office establishment (salaries, £573 13 1.—Rent and taxes, £106 10 0.)		680	3	1
Engineering department		520	9	0
Interest		5966	14	11
Locomotive power.	Fuel and watering, £2957 8 0—Oil, tallow, hemp, &c. £507 3 1.—Repairs and materials, £5947 6 5.—Enginemen's wages, £1170 18 8.	10,582	16	2
Maintenance of way (wages, £3929 8 0.—Blocks, sleepers, chairs, &c. £2668 12 3—Ballast, £733 0 3		7331	0	6
Office establishment (salaries, £652 8 6.—Rent and taxes, £77 9 2.—Stationary, &c. £81 10 5)		811	8	1
Police and gatekeepers		1356	9	11
Petty disbursements		75	1	0
Rent		1840	1	10
Stationary engine and tunnel disbursements new tunnel rope, £330 10 8.—Coal, £265 7 0.—Wages, £290 9 9.—Repairs, oil, tallow, hemp &c. £165 8 9		1051	16	2
Taxes and rates		1109	14	9
Wagon disbursements.	Smiths' and joiners' wages, £586 6 7.—Iron, timber, &c. £265 0 9.—Canvass, Paint, &ç. for sheets, £155 10 10	1006	18	2
		47,770	15	5
Deduct credits		1,112	4	1
		£46,658	11	4

Nett profits for six months - - -	£28,048 4 9
Dividend per share of £100 - -	4 0 0
Nett profit on Sunday travelling per share of £100	0 4 8

HALF-YEAR ENDING 31ST DECEMBER, 1832.

		Tons.
Merchandise between Liverpool and Manchester		61,995
Ditto to different parts of the road, including the Warrington and Wigan trade - -		6,011
Ditto between Liverpool and Bolton -		18,836
Coals from various parts of the road to Liverpool or Manchester - - - - -		39,940
Number of passengers booked in the Company's offices - - - -	182,823	
Number of trips of 30 miles performed by the locomotive engines with passengers	3,363	
Do. with goods - - - -	1,679	
Do. with coals - - - - -	211	

Receipts.

Coaching department - - -	43,120 6 11	
General merchandise - - -	34,977 12 7	
Coal department - - -	2,804 3 4	
		£80,902 2 10

Expenses.

Bad debt account - - - - -		81 6 0
Coach disbursements.	Guards' and porters' wages, £1173 19 6.—Parcel carts and drivers' wages, £375 14 4—Materials for repairs, £464 1 9.—Men's wages, repairing £613 18 1.—Gas, oil, tallow, &c. £232 11 7.—Duty on passengers, £985 19 1.—Stationary and petty expenses, £414 19 7.	4261 3 11
Carrying disbursements.	Salaries, £1822 13 2.—Porters', &c. wages, £3925 7 4.—Gas, oil, tallow, cordage, &c. £296 11 7.—Repairs to jiggers, trucks, stations, &c. £398 3 11.—Stationary and petty expenses, £540 13 5.	6983 9 5
Coal ditto - - - - - -		27 2 10
Cartage (Manchester) - - -		2744 18 7
Charge for direction - - -		295 1 0
Compensation (coaching) - - -		209 15 11
Ditto (carrying) - - - - -		150 19 11
Coach office establishment, (Salaries £556 3 10.—Rent and taxes, £75 15 2) - -		631 19 0
Engineering department - - -		450 0 0
Interest - - - - - -		4555 15 7

Locomotive power.	Fuel and watering, £3848 10 8.—Oil, tallow, hemp, &c, £661 1 9.—Materials for repairs, £3723 9 7.—Men's wages, repairing, £3352 16 2.—Engine and firemen's wages, £1060 11 6	12,646	9	8			
Law disbursements		118	3	8			
Maintenance of way (wages, £3675 16 5.—Block, sleepers, chairs, &c. £2355 17 1.—Ballast, &c. £846 10 9)		6878	4	3			
Petty disbursements		66	2	0			
Rent		1246	5	0			
Stationary engine and tunnel disbursements, (Coal, £209 15 3.—Engine and brakemen's wages, £316 7 5.—Repairs, gas, oil, tallow, &c. £326 14 7)		852	17	3			
Taxes and rates		3483	18	2			
Wagon disbursements.	Smith' and joiners' wages, £583 0 5.—Iron, timber, &c. £350 12 10—Canvass, paint, &c. for sheets, £31 0 0.	964	13	3			
Office establishment (Salaries, £623 18 0.—Rent, £85 0 0.—Stationary, £18 9 0)		727	7	0			
Police ditto		902	16	5			
					£48,278	8	10

Nett profit for six months	32,623	14	0
Dividend per share of £100	4	4	0
Nett profit on Sunday travelling per share of £100	0	4	0

HALF-YEAR ENDING 30TH JUNE, 1833.

		Tons.
Merchandise between Liverpool and Manchester		68,284
Ditto to different parts of the line, including Warrington and Wigan		8,712
Ditto between Liverpool, Manchester and Bolton		19,461
Coals from various parts to Liverpool and Manchester		41,375
Total number of passengers booked in the Company's offices	171,421	
Number of trips of 30 miles performed by the locomotive engines with passengers	3,262	
Ditto with merchandise	2,244	

Receipts.

Coaching department	£44,130	17	2			
Merchandise ditto	39,301	17	3			
Coal ditto	2,638	15	9			
				£86,071	10	2

Expenses.

Advertising account	50	8	7
Bad debt account	176	18	6

Coach disbursements.	Guards' and porters' wages, L1150 4 0.—Parcel carts, horse keep and drivers' wages, L401 18 6.—Materials for repairs, L383 15 11.—Men's wages, repairing, L758 10 6.—Gas, oil, tallow, cordage, &c. L324 4 0.—Duty on passengers, L2466 15 4.—Stationary and petty expenses, L236 15 6.—Taxes on Offices, stations, &c. L112 18 4.	5,835	2	1
Carrying disbursements.	Agents' and clerks' salaries, L1703 17 6.—Porters' and brakesmen's wages, horse keep, &c. L4687 9 7.—Gas, oil, tallow, cordage, &c. L648 4 11.—Repairs to jiggers, trucks, stations, &c. L405 13 1.—Stationary and petty expenses, L336 9 0.—Taxes, insurance, &c. on offices and stations, L798 1 8.	8,579	15	9
Coal disbursements		120	16	1
Cartage (Manchester) . . .		2460	16	1
Charge for direction . . .		252	0	0
Compensation (coaching) . . .		38	1	2
Compensation (carrying) . . .		1033	18	3
Coach office establishment, (Agents' and clerks' salaries, L577 19 6.—Rent and taxes, L102 17 1) . . .		680	6	7
Engineering department . . .		441	17	4
Interest		5,367	11	9
Locomotive power.	Coke and carting, L2795 4 5.—Wages to coke fillers, and watering engines, L338 16 10—Gas, oil, tallow, hemp, &c. L760 15 2.—Copper and brass tubes, iron, timber, &c. for repairs, L3290 8 8.—Men's wages, repairing, L4115 0 8.—Enginemen and firemen's wages, L892 4 4.—Out-door repairs to engines, L943 6 8.—Two new engines, "Leeds" and "Firefly," L1580 0 0.	14,715	16	9
Maintenance of way (wages, L3648 18 5.—Blocks, sleepers, chairs, &c. L2052 5 11.—Ballast and draining, L1013 4 11) .		6,714	9	3
Office establishment (Salaries, L624 19 0.—Rent and taxes, L62 18 6.—Stationary, &c. L59 19 5)		744	16	11
Police		950	4	7
Petty disbursements . . .		70	0	0
Rent		601	15	8

Repairs to walls and fences - -	296	4	0			
Stationary engine and tunnel disbursements (Coal, L155 8 1.—Engine and brakesmen's wages, L363 8 10.—Repairs, gas, oil, tallow, &c. L340 15 11) - -	859	12	10			
Tax and rate - - - - -	1,891	0	7			
Wagon disbursements, (Smiths' and joiners' wages, L598 3 1.—Iron, timber, &c. L320 1 4.—Cordage, paint, &c. for sheets, L82 7 3) - - - - -	1,000	11	8			
Cartage (Liverpool) - -	18	4	6			
				£52,900	9	1
Nett profit for six months - - -				33,171	1	1
Dividend per share of L100 - - -				4	4	0
Nett profit on Sunday travelling per share of L100				0	3	6

HALF-YEAR ENDING 31ST DECEMBER, 1833.

		Tons.
Merchandise between Liverpool and Manchester		69,806
Ditto to and from different parts of the line, including Warrington and Wigan -		9,733
Ditto between Liverpool, Manchester, and Bolton - - - - - -		18,708
Coal from various parts to Liverpool and Manchester - - - - - -		40,134
Total number of passengers booked at the Company's offices - -	215,071	
Number of trips of 30 miles performed by the locomotive engines with passengers	3,253	
Do. with merchandise - -	2,587	

Receipts.

Coaching department - - -	L54,685	6	11			
Merchandise ditto - -	39,957	16	8			
Coal ditto - - - - -	2,591	6	6			
				£97,234	10	1

Expenses.

Advertising account - - -	6	10	0
Bad debt account - - - - -	374	10	1
Coach disbursements. { Guards' and porters' wages, L1168 4 6—Parcel carts, horse keep, and drivers' wages, L361 1 7.—Materials for repairs, L689 12 6.—Men's wages, repairing, L1041 1 3. —Gas, oil, tallow, cordage, &c. L196 4 11.—Duty on passengers, L3224 11 11.—Stationary and petty expenses, L277 4 5.—Taxes on offices, stations, &c. L116 0 8.—Guards' clothes, L64 15 0. }	7,138	16	9

Carrying disbursements.	Agents' and clerks' salaries, *L*1728 16 9.—Porters' and brakesmen's wages, horse keep, &c. *L*5006 6 10.—Gas, oil, tallow, cordage, &c. *L*529 17 0.—Repairs to jiggers, trucks, stations, &c. *L*366 9 11.—Stationary and petty expenses, *L*429 5 1.—Taxes and insurance on offices, &c. *L*456 17 7.—Sacks for grain, *L*110 3 10.	8,627	17	0
Coal disbursements	- - -	82	0	9
Cartage (Manchester)	- - -	3,173	18	0
Charge for direction	- - -	312	18	0
Compensation (coaching)	- - -	142	4	8
Compensation (carrying)	- - -	223	10	11
Coach office establishment, (Agents' and clerks' salaries, *L*602 6 8,—Rent, *L*30)		632	6	8
Engineering department	- -	319	3	4
Interest	- - - - -	5,140	6	4
Locomotive power.	Coke and carting, *L*3197 4 4.—Wages to coke fillers and waterers, *L*348 8 5.—Gas, oil, tallow, hemp, cordage, &c. *L*865 14 9.—Brass and copper, iron, timber, &c. for repairs, *L*3755 3 7.—Men's wages, repairing, *L*4401 4 10—Engine and firemen's wages, *L*784 8 5.—Out-door repairs to engines, *L*613 3 9.	13,965	8	1
Maintenance of Way.	Wages to plate-layers, joiners, &c. *L*2937 19 2.——Stone, blocks, sleepers, keys, chairs, &c. *L*2411 2 4.—Ballasting and draining, *L*925 16 11.—New rails, *L*150 16 3.	6,425	14	8
Office establishment, (Salaries, *L*607 2 0.—Rent and taxes, *L*75 14 3.—Stationary and printing, *L*22 7 8.—Stamps, *L*17 2 3	-	722	6	2
Police	- - - - -	1,022	7	6
Petty disbursements	- - -	61	19	6
Rent	- - - - - -	603	10	8
Repairs to walls and fences	- - -	665	3	4
Stationary engine and tunnel disbursements, (Coal, *L*302 6 5.—Engine and brakesmen's wages, *L*319 11 2.—Repairs, gas, oil, tallow, &c. *L*419 15 5.—New rope for tunnel, *L*266 3 6)	- - -	1,307	16	6
Tax and rate	- - - -	3,409	11	0
Wagon disbursements.	Smiths' and joiners' wages, *L*718 19 7.—Iron, timber, castings, &c. *L*700 9 1.—Cordage, paint, &c. *L*28 5 2.—Canvass for sheets, *L*163 6 5.	1,611	0	2

Cartage (Liverpool)	80 17 10	
Law disbursements	300 3 9	
		£56,350 1 9

Nett profit for six months	40,884 8 4
Dividend per share of *L*100	4 10 0
Nett profit on Sunday travelling per share of *L*100	0 5 3
Reserved fund formed in the six months . .	4,088 8 10

HALF-YEAR ENDING 30th JUNE, 1834.

		Tons.
Merchandise between Liverpool and Manchester		69,522
To and from different parts of the road, including Warrington and Wigan		15,201
Between Liverpool, Manchester and Bolton . .		19,633
Coal to Liverpool and Manchester		46,039
Number of passengers booked at the Company's offices	200,676	
Number of trips of 30 miles performed by the locomotive engines with passengers	3,317	
Ditto with merchandise	2,499	

Receipts.

Coaching department	£50,770 16 11	
Merchandise ditto	41,087 19 5	
Coal ditto	2,925 15 11	
		£94,784 12 0

Expenses.

Advertising account		16 15 0
Bad debt ditto		75 12 3
Coach disbursements.	Guards' and porters' wages, *L*1167 11 10.—Parcel carts, horse keep and drivers' wages, *L*359 13 0.—Materials for repairs, *L*1007 9 7.—Men's wages, repairing, *L*1221 15 5 —Gas, oil, tallow, cordage, &c. *L*358 15 6.—Duty on passengers, *L*3008 1 11.—Stationary and petty expenses *L*165 2 5.—Taxes, insurance, &c. on offices and stations, *L*65 8 11.	7,353 18 7
Carrying disbursements	Agents' and clerks' salaries, *L*1740 14 2.—Porters' and brakesmen's wages, horse-keep, &c. *L*5397 8 5.—Gas, oil, tallow, cordage, &c. *L*708 17 4.—Repairs to jiggers, trucks, s'ations, &c. *L*716 2 8.—Stationary and petty expenses, *L*290 3 2.—Taxes, insurance, &c. on offices and stations, *L*469 6 2.	9,322 11 11

	£	s.	d.			
Coal disbursements	45	1	0			
Cartage (Manchester)	2,988	6	2			
Charge for direction	289	16	0			
Compensation (coaching)	26	3	10			
Compensation (carrying)	645	6	0			
Coach office establishment, (Agents' and clerks' salaries, L615 1 11.—Rent and taxes, L63 1 1	678	3	0			
Engineering department	352	10	0			
Interest	5,546	4	0			
Locomotive power { Coke and carting, L2882 11 4.—Wages to coke fillers, and watering engines, L386 19 5.—Gas, oil, tallow, hemp, &c. L881 18 4.—Copper and brass tubes, iron, timber, &c. for repairs, L4140 19 6.—Men's wages for repairing, L5432 8 8.—Enginemen and firemen's wages, L836 14 3.—A new engine, L700.—Lathe engine, boiler, and fixing for repairing sheds and watering stations, L380 6 4. }	15,641	17	10			
Law disbursements	100	0	0			
Maintenance of Way { Wages and small materials, L4221 2 5.—Stone, blocks, sleepers, &c. L1482 18 7.—New rails and chairs, points, crossings, &c. L3153 14 5.—Ballast and leading, L493 2 0. }	9,350	17	5			
Office establishment, (Salaries L818 14 4.—Rent and taxes, L58 8 0)	877	2	4			
Police	1,016	18	1			
Petty disbursements	60	0	0			
Rent	363	11	11			
Stationary engine and tunnel disbursements, (Coal, L327 12 1.—Engine and brakesmen's wages, L385 7 0.—Repairs, gas, oil, tallow, &c. L273 11 1)	986	10	2			
Tax and rate	1,778	16	10			
Wagon disbursements. { Smiths' and joiners' wages, L773 3 8.—Iron, timber, &c. L728 12 4.—Cordage, paint, &c. L109 19 2.—Canvass for sheets, L240, }	1,851	15	2			
Repairs to walls and fences	644	0	11			
Cartage (Liverpool)	80	17	6			
				£60,092	15	11
Nett profit for six months				34,691	16	4
Dividend per share of L100				4	10	0
Nett profit on Sunday travelling per share of L100				0	5	2

A NEW THEORY

OF THE

STEAM ENGINE,

AND THE

MODE OF CALCULATION BY MEANS OF IT,

OF

THE EFFECTIVE POWER &c. OF

EVERY KIND OF STEAM ENGINE, STATIONARY OR LOCOMOTIVE.

BY

THE CHEVALIER G. DE PAMBOUR.

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A NEW THEORY

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In our Treatise on Locomotive Engines, the first edition of which appeared in the beginning of 1835, was published the basis of a new theory of the steam engine. We then limited ourselves to showing its application to locomotives, merely announcing that it was no less indispensable for calculating with exactitude both the effects and the proportions of stationary steam engines of every kind. The memoir of which we now offer an analysis, and which was read by parts at the *Institute Royale* of France, from February till the close of the year, 1837, has for its object to give a farther development of that theory, and to extend it to the various systems of steam engines in use. It consists of three parts, namely:—

Part i.—Proofs of the inexactitude of the ordinary methods of calculation, used to determine the effects or the proportions of steam engines; and a succinct exposition of the method proposed.

Part ii.—General formulæ for the calculation of the effects, &c. of rotative, stationary or locomotive, high or low pressure, expansive or unexpansive, condensing or uncondensing steam engines, according to the proposed theory.

Part iii.—Special application of these formulæ to the divers systems of steam engines in use.

PART I.

PROOFS OF THE INEXACTITUDE OF THE ORDINARY METHODS, AND EXPOSITION OF THE ONE PROPOSED.

§ 1. *Mode of calculation hitherto in use.*—All the problems in the application of steam engines merge into these three—

The velocity of the motion being given, to find the load the engine will move at that velocity.

The load being given, to find the velocity at which the engine will move that load;

And, the load and the velocity being given, to find the vaporization necessary, and consequently the area of heating surface requisite for the boiler, in order that the given load be set in motion at the given velocity.

The problem, which consists in determining the useful effect to be expected from an engine of which the number of strokes of the piston per minute is counted, that is, whose velocity is known, evidently amounts to determining the effective load corresponding to that velocity; for that load being once known, by multiplying it by the velocity we have the useful effect required.

According to the mode of calculation hitherto admitted, when it is wanted to know the useful effect an engine will produce at a given velocity, or, in other words, the effective load that it will set in motion at that velocity, the area of the cylinder is multiplied by the velocity of the piston, and that product by the pressure of steam in the boiler; this gives, in the first place, what is called the theoretical effect of the engine. Then, as experience has shown that steam engines can never completely produce this theoretical effect, it is reduced in a certain proportion, indicated by a constant number, which is the result of a comparison between the theoretical and practical effects of some engines

previously put to trial; and thus is obtained the number which is regarded as the practical effect of the engine, or the work it really ought to execute.

A mode perfectly similar is followed, for determining the vaporization which an engine ought to produce in order to produce a desired effect; that is to say, for resolving the third of the problems which we have presented above. As to the second of these problems, that which consists in determining the velocity the engine will assume under a given load, no solution of it has been proposed in this way, and we shall expose, farther on, some fruitless essays that have been made to resolve it in another way.

As in the above-mentioned calculation no account is taken of friction, nor of some other circumstances which appear likely to diminish the power of the engine, the difference observed between the theoretical and the practical result excites no surprise, and is readily attributed to the circumstances neglected in the calculation.

§ 2. *First objection against this mode of calculation.*—This mode of calculation is liable to many objections, but for the sake of brevity we limit ourselves to the following:—

The coefficient adopted to represent the ratio of the practical effects to the theoretical, varies from $\frac{1}{3}$ to $\frac{2}{3}$, according to the various systems of steam engines; that is to say, that from $\frac{2}{3}$ to $\frac{1}{3}$ of the power exerted by the machine is considered to be absorbed by friction and divers losses. Not that this friction and these losses have been measured and found to be so much, but merely because the calculation that had been made, and which might have been inexact in principle, wanted so much of coinciding with experience.

Now it is easy to demonstrate, that the friction and losses which take place in a steam engine can never amount to $\frac{2}{3}$, nor to $\frac{1}{3}$ of the total force it developes. It will suffice to cast an eye on the explanation attempted, on this point, by Tredgold, who follows this method in his Treatise on Steam

Engines.* He says (art. 367,) that, for high pressure engines, a deduction of $\frac{4}{10}$ must be made from the *total* pressure of the steam, which amounts to a deduction of $\frac{5}{10}$ on the ordinary *effective* pressure of such engines; and to justify this deduction, which however is still not enough to harmonize the theoretical and practical results in many circumstances, he is obliged to estimate the friction of the piston, with the losses or waste, at $\frac{2}{10}$ of the power, and the force requisite for opening the valves and overcoming the friction of the parts of the machine, at $\frac{6}{100}$ of that power. Reflecting that these numbers express fractions of the gross power of the engine, we must readily be convinced that they cannot be correct; for, in supposing the engine had a useful effect of 100 horses, which, from the reduction or coefficient employed, supposes a gross effect of 200 horses, 12 would be necessary to move the machinery, 40 to draw the piston, &c.! The exaggeration is evident.

Besides, in applying this evaluation of the friction to a locomotive engine, which is also a high pressure steam engine, and supposing it to have 2 cylinders of 12 inches diameter, and to work at 75 ℔s. total pressure, which amounts to 60 ℔s. effective pressure, per square inch, we find that from the preceding estimate, the force necessary to draw the piston would be 5650 ℔s., whereas our own experiments on the locomotive engine, the *Atlas*, which is of these dimensions, and works at that pressure, demonstrate that the force necessary to move, not only the two pistons, but all the rest of the machinery, including the waste, &c., is but 48 ℔s. applied to the wheel, or 283 ℔s. applied on the piston.

It is then impossible to admit, that in steam engines the friction and losses can absorb the half, nor the third, much

* The author here refers to the first edition of "Tredgold on the Steam Engine;" in the new edition just published the algebraic parts are transformed by the editor into easy practical rules, accompanied by examples familiarly explained for the working engineer.

less the $\frac{3}{8}$ of the total power developed; and yet there do occur cases wherein, to reconcile the practical effects with the theoretical ones thus calculated, it would be necessary to reduce the latter to the fourth part, and even to less; and what is more, it often happens, that the same engine which in one case requires a reduction of $\frac{3}{4}$, will not in other cases need a reduction of more than about $\frac{1}{8}$. This is observed in calculating the effects of locomotive engines at very great velocities, and afterwards at very small ones.

There is no doubt, then, that the difference observed between the theoretical effect of an engine and the work which it really performs, does not arise from so considerable a part of the applied force being absorbed by friction and losses, but rather from the error of calculating in this manner the theoretical effect of the machine. In effect, this calculation supposes that the motive force, that is, the pressure of the steam *against the piston or in the cylinder*, is the same as the pressure of the steam in the boiler; whereas we shall presently see, that the pressure in the cylinder may be sometimes equal to that of the boiler, sometimes not the half nor even the third of it, and that it depends on the resistance overcome by the engine.

§ 3. *Formulæ proposed by divers authors to determine the velocity of the piston under a given load, and proofs of their inexactitude.*—We have said that this problem was not resolved by the foregoing method. The following are the attempts made to that end by another way. Tredgold, in his Treatise on Steam Engines (art. 127 and following,) undertakes to calculate the velocity of the piston from considerations deduced from the velocity of the flowing of a gas, supposed under a pressure equal to that of the boiler, into a gas supposed at the pressure of the resistance. He concludes from thence, that the velocity of the piston would be expressed by this formula,

$$V = 6{\cdot}5 \sqrt{h},$$

in which V is the velocity in feet per second, and h stands for the difference between the heights of two homogeneous

columns of vapour, one representing the pressure in the boiler, the other that of the resistance. But it is easily seen, that this calculation supposes the boiler filled with an inexhaustible quantity of vapour, since the effluent gas is supposed to rush into the other with all the velocity it is susceptible of acquiring, in consequence of the difference of pressure. Now such an effect cannot be produced, unless the boiler be capable of supplying the expenditure, however enormous it might be. This amounts consequently to supposing that the production of steam in the boiler is unlimited. But, in reality, this is far from being the case. It is evident that the velocity of the piston will soon be limited by the quantity of steam producible by the boiler in a minute. If that production suffice to fill the cylinder 200 times in a minute, there will be 200 strokes of the piston per minute; if it suffice to fill it 300 times, there will be 300 strokes. It is then the vaporization of the boiler which must regulate the velocity, and no calculation which shall exclude that element can possibly lead to the true result; consequently the preceding formula cannot be exact.

This is why, in applying this formula to the case of an ordinary locomotive engine of the Liverpool Railway with a train of 100 tons, the velocity the engine ought to assume is found to be 734 feet per second, instead of twenty miles an hour, or five feet per second, which is its real velocity.

Again, in his Treatise on Railways (page 83,) Tredgold proposes the following formula, without in any way founding it on reasoning or on fact:

$$V = 240 \sqrt{\frac{l P}{W}},$$

in which V is the velocity of the piston in feet per minute, l the stroke of the piston, P the effective pressure of the steam in the boiler, and W the resistance of the load. But as this formula makes no mention either of the diameter of the cylinder, or of the quantity of steam supplied by the boiler in a minute, it clearly cannot give the velocity sought; for if it could, the velocity of an engine would be

the same with a cylinder of one foot diameter as with a cylinder of four feet, which expends sixteen times as much steam. The area of heating surface, or the vaporization of the boiler, would be equally indifferent: an engine would not move quicker with a boiler vaporizing a cubic foot of water per minute, than with one that should vaporize but $\frac{1}{4}$ or $\frac{1}{20}$. Hence this formula is without basis.

Wood, in his Treatise on Railways (page 351,) proposes the following formula also, without discussion,

$$V = 4 \sqrt{\frac{l P}{W}},$$

where V is the velocity of the piston in feet per minute, l the length of stroke of the piston, W the resistance of the load, and P the surplus of the pressure in the boiler, over and above what is necessary to balance the load W. This formula being liable to the same objections as the preceding, is also demonstrated inadmissible *à priori.*

Consequently, of the three fundamental problems of the calculation of steam engines, two have received inaccurate solutions by means of the coefficients, and the third, as we have just seen, has received no solution at all.

§ 4. *Succinct exposition of the proposed theory.*—After having made known the present state of science, with regard to the theory and estimation of the effective power of steam engines, it remains to exhibit the theory we apply to them ourselves.

It is well known, that in every machine, when the effort of the motive power becomes superior to the resistance, a slow motion is created, which quickens by degrees till the machine has attained a certain velocity, beyond which it does not go, the motive power being incapable of producing greater velocity with the mass it has to move. Once this point attained, which requires but a very short space of time, the velocity continues the same, and the motion remains uniform as long as the effort lasts. It is from this point only that the effects of engines begin to be reckoned, because they are never employed but in that state of uni-

form motion; and it is with reason that the few minutes, during which the velocity regulates itself, and the transitory effects which take place before the uniform velocity is acquired, are neglected.

Now, in an engine arrived at uniform motion, the force applied by the motive power forms strictly an equilibrium with the resistance; for if that force were greater or less, the motion would be accelerated or retarded, which is contrary to the hypothesis. In a steam engine the force applied by the motive agent is nothing more than the pressure of the steam *against the piston* or *in the cylinder*. The pressure therefore in the cylinder is strictly equal to the resistance of the load against the piston.

Consequently the steam, in passing from the boiler to the cylinder, may change its pressure, and assume that which is represented by the resistance of the piston. This fact alone exposes all the theory of the steam engine, and in a manner lays its play open.

From what has been said, the force applied on the piston, or the pressure of the steam in the cylinder, is therefore strictly regulated by the resistance of the load against the piston. Consequently calling P′ the pressure of the steam in the cylinder, and R the resistance of the load against the piston, we have as a first analogy,

$$P' = R.$$

To obtain a second relation between the data and the quæsita of the problem, we shall observe that there is a necessary equality between the quantity of steam produced, and the quantity expended by the machine; the proposition is self-evident. Now if we express by S the volume of water vaporized in the boiler per minute, and effectively transmitted to the cylinder, and by m the ratio of the volume of the steam generated under the pressure P of the boiler, to the volume of water which produced it, it is clear that

$$m\,S$$

will be the volume of steam formed per minute in the boiler.

This steam passes into the cylinder, and there assumes the pressure P′; but if we suppose that, in this motion, the steam preserves its temperature in passing from the boiler to the cylinder, or from the pressure P to the pressure P′, its volume increases in the inverse ratio of the pressures. Thus the volume m S of steam furnished per minute by the boiler will, when transmitted to the cylinder, become

$$m\,\mathrm{S}.\frac{\mathrm{P}}{\mathrm{P}'}.$$

On another hand, v being the velocity of the piston, and a the area of the cylinder, $a\,v$ will be the volume of steam expended by the cylinder in a minute. Wherefore, by reason of the equality which necessarily exists between the production of the steam and the expenditure, we shall have the analogy of

$$a\,v = m\,\mathrm{S}.\frac{\mathrm{P}}{\mathrm{P}'};$$

which is the second relation sought.

Consequently, by exterminating P′ from the two equations, we shall have as a definitive analytic relation among the different data of the problem:

$$v = \frac{m\,\mathrm{S}}{a}.\frac{\mathrm{P}}{\mathrm{R}}.$$

This relation is very simple, and suffices for the solution of all questions regarding the determination of the effects or the proportions of steam engines. As we shall develope its terms hereafter, in taking it up in a more general manner, we content ourselves to leave it for the present under this form, which will render the discussion of it easier and clearer.

The preceding equation gives us the velocity assumed by the piston of an engine under a given resistance R. If, on the contrary, the velocity of the motion be known, and it be required to calculate what resistance the engine will move at that velocity, it will suffice to resolve the same equation with reference to R, which will give

$$R = \frac{m S P}{a v}.$$

Finally, supposing the velocity and the load to be given beforehand, and that it be desired to know what vaporization the boiler should have to set the given load in motion at the prescribed velocity, it will still suffice to draw from that analogy the value of S, which will be

$$S = \frac{a v R}{m P}.$$

On these three determinations we rest for the moment, because, as will soon appear, they form the basis of all the problems that can be proposed on steam engines.

§ 5. *New proofs of the exactitude of this theory, and of the inaccuracy of the ordinary mode of calculation.*—The theory just developed demonstrates that the steam may be generated in the boiler at a certain pressure P, but that in passing to the cylinder it necessarily assumes the pressure R, strictly determined by the resistance to the piston, whatever the pressure in the boiler may be. Consequently, according to the intensity of that resistance, the pressure in the cylinder, far from being equal to that in the boiler, or from differing from it in a certain constant ratio, may at times be equal to it, and at other times very considerably different. Hence those who, in performing the ordinary calculation, consider the force applied on this piston as indicated by the pressure in the boiler, begin by introducing into their calculation an error altogether independent of the real losses to which the engine is liable. To this cause, then, and not to the friction and losses, which can form but the smallest part of it, must be attributed the enormous difference which, in this mode of calculation, is found between the theoretical effect of the engine, and the work which it really executes.

We have already proved the mode of action of the steam in the cylinder by the consideration of uniform motion; but in examining what passes in the engine, we shall immediately find many other proofs.

1st. The steam, in effect, being produced at a certain

degree of pressure in the boiler, passes into the tube of communication, and thence into the cylinder. It first dilates, because the area of the cylinder is from ten to twenty-five times that of the tube; but it would promptly rise to the same degree as in the boiler, were the piston immoveable. But as the piston, on the contrary, opposes only a certain resistance, determined by the load sustained by the engine, it will yield as soon as the elastic force of the steam in the cylinder shall have attained that point. The piston, in consequence, will be a valve to the cylinder. Hence the pressure in the cylinder can never exceed the resistance of the piston, for that would be supposing a vessel full of steam, in which the pressure of the steam would be greater than that of the safety valve.

2nd. Were it true, that the steam flowed into the cylinder, either at the pressure of the boiler, or at any other pressure which were to that of the boiler in any fixed ratio, as the quantity of steam generated per minute in the boiler would then flow at an identical pressure in all cases, and would consequently fill the cylinder an identical number of times per minute; it would follow, that as long as the engine should work with the same pressure in the boiler, it would assume the same velocity with all loads. Now we know that precisely the contrary takes place, the velocity increasing when the load diminishes; and the reason of it is, that when the load is half, the steam flowing also at a half pressure into the cylinder, and consequently acquiring a volume double what it had before, will serve for double the number of strokes of the piston.

3rd. Applying the same reasoning inversely, we perceive that were the pressure in the cylinder really bearing a constant ratio to that in the boiler, or if it be preferred, constant so long as that in the boiler did not vary, we should, in calculating the effort of which the engine would be capable, always find it the same, whatever be the velocity of the piston. Thus, at any velocity whatever, the engine would always be capable of drawing the same load;

which experience again contradicts, for the greater the velocity of the piston, the lower the pressure of the steam in the cylinder, whence results, that the load of the engine lessens at the same time.

4th. Another no less evident proof of this is easily adduced. Were it true that the pressure in the cylinder were to that in the boiler in any fixed proportion, since the same locomotive engine always requires the same number of revolutions of the wheel, or the same number of strokes of the piston to traverse the same distance, it would follow that, as long as those engines worked at the same pressure, they would consume in all cases the same quantity of water for the same distance. Now the quantity of water, far from remaining constant, decreases on the contrary with the load, as may be seen by the experiments we have published on this subject. Here therefore again it is proved, that, notwithstanding the equality of pressure in the boiler, the density of the steam expended follows the intensity of the resistance, that is to say, the pressure in the cylinder is regulated by that resistance.

5th. Similarly, the consumption of fuel being in proportion to the vaporization effected, it would follow, if the ordinary theory were exact, that the quantity of fuel consumed by a given locomotive, for the same distance, would always be the same, with whatever load. Now we again find by experience that the quantity of fuel diminishes with the load, conformably to the explanation we have given of the effects of the steam in the engine.

6th. It is again clear that if the pressure in the cylinder were, as it is believed, constant for a given pressure in the boiler, that so soon as it was recognised that an engine could draw a certain load with a certain pressure, and communicate to it a uniform motion, it would follow, that the same engine could never draw a less load with the same pressure, without communicating to it a velocity indefinitely accelerated; since the power, having been found equal to the resistance of the first load, would necessarily be superior

to that of the second. Now experience proves, that in the second case the velocity is greater, but that the motion is no less uniform than in the first; and the reason of this is, that though the steam may indeed be produced in the boiler at a greater or less pressure, and that it matters little, yet on passing into the cylinder, it always assumes the pressure of the resistance, whence results that the motion must remain uniform as before.

7th. Finally, in looking over our experiments on locomotives, it will be seen that the same engine will sometimes draw a light load with a very high pressure in the boiler, and sometimes a heavy load with a very low pressure. It is then impossible to admit, as the ordinary calculation supposes, that any fixed ratio *whatever* has existed between the two pressures. Moreover, the effect just cited is easy to explain, for it depends simply on this, that in both cases the pressure in the boiler was superior to the resistance on the piston; and it needed no more for the steam, generated at that pressure or at any other, satisfying merely that condition, to pass into the cylinder and assume the pressure of the resistance.

It is then visible, from these various proofs, that the pressure in the cylinder is strictly regulated by the resistance on the piston, and by nothing else; and that any method like that of the coefficients in the ordinary calculation, which tends to establish a fixed ratio between the pressure in the cylinder and that of the boiler, must necessarily be inexact.

§ 6. *Verification of the two modes of calculation by particular examples.*—We have sufficiently demonstrated the want of basis of the ordinary calculation; but as the inaccuracy we have just exposed in that method might by some be supposed to be of slight importance, and they might conceive that, in practical examples, it amounted to the obtaining of results, which if not quite exact, were at least very near the truth, we will now attempt to apply it to some particular cases.

The coefficient of reduction for high pressure engines, working without expansion and without condensation, not being given by the authors who have treated on these subjects, we propose, in order to determine it, the two following facts which took place before our eyes:—

I. The *Leeds* locomotive engine, which has two cylinders eleven inches in diameter, stroke of the piston sixteen inches, wheel five feet in diameter, drew a load of 88·34 tons, in ascending a plane inclined 1 in 1300, at the velocity of 20·34 miles an hour; the effective pressure in the boiler being 54 lbs. per square inch, or the total pressure 68·71 lbs. per square inch.

II. The same day, the same engine drew a load of 38·52 tons in descending a plane inclined 1 in 1094, at the velocity of 29·09; the pressure in the boiler being precisely the same as in the preceding trial, and the regulator open to the same degree. These experiments may be seen in pages 201 and 202 of our Treatise on Locomotives.

If on one hand be reckoned, according to the ordinary method, the theoretic effort applied to the piston, and on the other hand the effect really produced, viz., the resistance opposed by the load *plus* that of the air against the train, we find, on referring the pressure and the area of the pistons to the foot square:—

1st case.—Theoretic effort applied on the piston, according to the ordinary calculation $1{\cdot}32 \times (68{\cdot}71 \times 144)$ . .	13,060 lbs.
Real effect	8,846
Coefficient of correction . .	0·68
2nd case.—Theoretic effort, the same as above	13,060
Real effect	6,473
Coefficient of correction . .	0·50

The *mean* coefficient, to apply to the total pressure, to convert the theoretic effects to the practical, is then ·59.

We find, then, three very different coefficients: choose the first case, then an error occurs in the second; choose the second, and an error must arise in the first; by taking the third, you will only divide the error between the two. In every way an error is inevitable, and that alone suffices to prove that every method, like the ordinary one, which consists in the use of a *constant* coefficient, is necessarily inexact, whatever be the coefficient chosen, and to whatever engine the application be made; for it is evident that the same fact would occur in every kind of steam engine. Only that it might be less marked, if the velocities at which the engine were taken were less different; and this is what has hitherto prevented the error of this method from being perceived, for all the engines of the same system being imitated from each other, and moving nearly at the same velocity, the same coefficient of correction seems tolerably to suit them, from the factitious limit that had been laid down for the speed of the piston.

Besides, in stationary engines, one cannot, for want of precise determinations of the friction, disengage in the result the part which is really attributable to it from that which constitutes a positive error. But here we may easily be convinced that neither of these coefficients of correction represents, as the ordinary theory would have it, the friction, losses, and various resistances of the machine; for direct experiments made on the engine under consideration, and noted in our Treatise on Locomotives, enable us to estimate separately all these frictions, losses, and resistances. Reckoning, then, the friction of the engine at 82 lbs. taking account besides of its additional friction per ton of load, and adding for each case the pressure subsisting on the opposite side of the piston by the effect of the blast pipe, we find, as the sum of the friction and indirect resistances—

1st case.—Friction	1,257 lbs.
or ·10 of the theoretic result.	
2nd case.—Friction	873 lbs.
or ·07 of the theoretic result.	

Thus we see that in each of the two cases, the friction and indirect resistances, omitted in the calculation, do not in reality amount to more than 10 or 7 hundredths of the theoretic result; and if we should be disposed to add to that $\frac{1}{20}$ or ·05, for the filling of the vacant spaces of the cylinder, which we could not estimate in lbs., it will be ·15 and ·12; whereas the coefficients of correction would raise them to ·32 in one case, and ·50 in the other; that is, to 2 and 4 times what they really are. If, then, from these coefficients, be deducted the true value of the friction and losses, it will appear that the theoretic error, introduced into the calculation under the denomination of friction, is 17 per cent. of the *total power of the engine* in the one case, and 38 per cent. in the other.

But it is to be remarked, that, from the preceding evaluations, viz., of the direct resistances first, and then of the friction and indirect resistances, we have, for each of the two cases in question, the sum of the total effects really produced by the machine, as follows:—

1st case.—Direct resistances	8,846 lbs.
Friction	1,257
	10,103
2nd case.—Direct resistances	5,473
Friction	873
	6,346

We are therefore enabled now to compare these effects produced with the results either of the ordinary calculation or of our theory.

1°. In applying the ordinary calculation with the mean coefficient ·56 determined above, and comparing its result with the real effect, we find—

1st case.—Effort applied on the piston, according to the ordinary calculation, 1·32 × (68·71 × 144) × ·59 .	7,705 lbs.
Effect produced, including friction and every resistance . . .	10,103
Error over and above the friction and resistances	2,398
2nd case.—Effort applied on the piston, according to the ordinary calculation, the same as above . . .	7,705 lbs.
Effect produced, including friction and every resistance . . .	7,346
Error over and above the friction and resistances	359
Mean error of the two cases . .	1,378

It is then evident what error would have been committed in calculating the effects of this engine from the coefficient ·59; but it is equally evident, that in applying any other coefficient *whatever*, the error would only transfer itself from one case to the other, without ever disappearing; and thus it is that the coefficient ·59 has almost annulled the error of the second case, by transferring it to the first.

To apply our formula with reference to the same problem, viz.:—

$$a\,R = \frac{m\,S\,P}{a\,v},$$

we have nothing more to do than to substitute for the letters their value, taking care to refer all the measures to the same unit. In making then these substitutions, which give

$P = 68 \cdot 71 \times 144$ lbs., $m = 411$, $a = 1 \cdot 32$, and observing that the effective vaporization of the engine has been $S = \cdot 77$ cubic foot of water per minute, we find,—

1st case.—Effort applied by the engine at the given velocity, according to our theory, $\frac{411 \times 0 \cdot 77 \times (68 \cdot 71 \times 144)}{298}$	10,507 lbs.
Effect produced, including friction and resistances, as above . .	10,103
Difference	404
2nd case.—Effort applied by the engine at the given velocity, according to our theory, $\frac{411 \times 0 \cdot 77 \times (68 \cdot 71 \times 144)}{434}$	7,215
Effect produced, including friction, &c.	7,346
Difference	131
Mean difference of the two cases . . .	267

It appears, then, that by this method, the useful effect is found with a difference only of 267 lbs., a very inconsiderable difference in experiments of this kind, wherein so much depends on the management of the fire.

2°. To continue the same comparison of the two theories, let it be required to calculate what quantity of water per minute the boiler ought to vaporize, to produce either the first effect or the second. The method followed by the ordinary theory, again consists in previously supposing that the volume described by the piston has been filled with steam at the same pressure as in the boiler, and then in applying to it a fractional coefficient to account for the losses.

Now, in the first case, the volume described by the piston at the given velocity, is $1 \cdot 32 \times 298 = 393$ cubic feet.

Had this volume been filled with steam at the pressure of the boiler, it would have required a vaporization of $\frac{393}{411} =$ ·96 cubic foot of water per minute. But the real vaporization was but ·77; wherefore, in the first case, the coefficient necessary to lead from the vaporization indicated by the ordinary calculation, to the real vaporization, $\frac{.77}{\cdot 96} = \cdot 81$.

In the second case, we find in the same manner, that the coefficient should be ·55; whence, in this problem, as in the preceding one, no constant coefficient whatever can suffice.

Performing, however, the calculation with the mean coefficient, ·68, we find,—

1st case.—Vaporization per minute, calculated by the ordinary theory, with the coefficient, $\frac{1\cdot 32 \times 298}{411} \times \cdot 68$	·65
Real vaporization	·77
Error	·12
2nd case.—Vaporization per minute, calculated by the ordinary theory, with the coefficient, $\frac{1\cdot 32 \times 434}{411} \times \cdot 68$	·95
Real vaporization	·77
Error	·18

The mean error committed is then $\frac{1}{5}$ of the vaporization, and being, as it is, a mean, it may, in extreme cases, become $\frac{2}{5}$, or amount to half of the whole vaporization.

This is the error committed in seeking a coefficient *expressly* for the vaporization. But when the coefficient, determined in the preceding case, that is, by the comparison of the theoretical and practical effects, is used as a divisor,

as by many authors it is, much greater errors are induced, which we will show by an example farther on.

In our theory, on the contrary, the vaporization necessary to set in motion the resistance a R at the velocity v, is given by the formula

$$S = \frac{a R \times v}{m P}.$$

We have then,—

1st case.—Vaporization calculated from our theory

$$\frac{10103 \times 298}{411 \times (68{\cdot}71 \times 144)}$$ - - - - - - ·74

Real vaporization - - - - - - - ·77

Difference - - - - - - - - ·03

2nd case.—Vaporization calculated from our theory,

$$\frac{7346 \times 434}{411 \times (68{\cdot}71 \times 144)}$$ - - - - - ·78

Real vaporization - - - - - - - ·77

Difference - - - - - - - - ·01

3°. Lastly, in the case of finding the velocity of the piston, supposing the resistance to be given, any method similar to the ordinary one must inevitably lead to errors; but we must dispense with comparison, since this problem has never been resolved, and we shall therefore in this case merely show the verification of our own theory. The formula relative to this problem is

$$v = \frac{m S P}{a R}.$$

We find then,—

1st case.—Velocity of the piston in feet per minute, calculated from our theory,

$\frac{411 \times \cdot77 \times (68\cdot71 \times 144)}{10103}$ - - -	310
Real velocity - - - - - - -	298
Difference - - - - - - - - -	12

2nd case.—Velocity of the piston from our theory,

$\frac{411 \times \cdot77 \times (68\cdot71 \times 144)}{7346}$ - -	426
Real velocity - - - - - - -	434
Difference - - - - - - - - -	8

It consequently appears, that in each of the three problems in question, our theory leads to the true result; whereas the ordinary theory, besides that it leaves the third problem unresolved, may, in the other two, lead to very serious errors.

Before abandoning this comparison, we request attention to an effect, in calculating by the ordinary theory, which we have already mentioned, but which is here demonstrated, viz., that this calculation gives the same force applied by the engine in both the cases considered, notwithstanding their difference of velocity; and such will always be the result, since the calculation consists merely in multiplying the area of the piston by the pressure in the boiler, and reducing the product in a constant proportion. This theory therefore, maintains, in principle, that the engine can always draw the same load at all imaginable velocities. Again we see, that, in the same calculation of the load or effort applied, the vaporization of the engine does not appear, which would imply that the engine would always draw the same load at all velocities, whatever might be the vaporization of the boiler, which is inadmissible.

We shall also remark, that in calculating by the ordinary theory the vaporization of the engine, no notice is taken of the resistance which the engine is supposed to

move; so that the vaporization necessary to draw a given load would be independent of that load—another result equally impossible.

To these omissions, therefore, or rather to these errors in principle, are to be attributed the variations observable in the results given of the ordinary theory in the examples proposed.

PART II.

ANALYTIC THEORY OF THE STEAM-ENGINE.

ARTICLE I.

CASE OF A GIVEN EXPANSION WITH ANY VELOCITY OR LOAD WHATEVER.

§ 1. *Of the change of temperature of the steam during its action in the engine.*—When an engine is at work, the steam is generated in the boiler at a certain pressure; it passes from thence into the cylinder, assuming a different pressure, and, in an expansive engine, the steam, after its separation from the boiler, continues to dilate itself more and more in the cylinder, till the piston is at the end of the stroke. It is generally supposed, that in all the changes of pressure which the steam may undergo, its temperature remains the same; and it is consequently concluded, that during the action of the steam in the engine, the density and volume of that steam follow the law of Mariotte, namely, that its volume varies in the inverse ratio of the pressure. This supposition greatly simplifies the formulæ; but, as reason and experience prove it to be altogether inexact, we are compelled to renounce it, and will substitute in its place another law, deduced from observation of the facts themselves.

We have recognised in a numerous series of experiments, by applying simultaneously a manometer and a thermometer, both to the boiler of a steam-engine, and also to the tube through which the steam, after having terminated its effect, escaped into the atmosphere, that during all its action in

the engine the steam remains in the state denoted by the name of saturated steam, that is, at the maximum density for its temperature. The steam in fact was produced in the boiler at a very high pressure, and escaped from the engine at a very low one; but on its issuing forth, as well as at the moment of its formation, the thermometer indicated the temperature corresponding to the pressure marked by the manometer, as if the steam were immediately generated at the pressure it had at that moment.

Thus during its whole action in the engine, the steam remains constantly at the maximum density for its temperature.

Now, in all steams, the volume depends at once on the pressure and the temperature; but in the steam at the maximum density, the temperature itself depends on the pressure. It should then be possible to express the volume of steam of maximum density, in terms of the pressure alone.

The equation which gives the volume of the steam in in any state whatever, in terms of the pressure and temperature, is very simple: it is deduced from Mariotte's law combined with that of M. Gay-Lussac. The equation which gives the temperature in terms of the pressure, for the steam at the maximum density, is also known: it has been deduced from the fine experiments of Messrs. Arago and Dulong on steam at high pressures, and from those of Southern and other experimenters on steam produced under low pressures. By eliminating then the temperature in these two equations, we shall obtain the analogy required, which will give immediately, with regard to steam at the maximum density, for its temperature, the volume in terms of the pressure alone.

But here arises the difficulty. The equation of the temperatures is not invariable; or rather, the same equation does not apply to all points of the scale. To be used with accuracy, it requires to be changed according as the pressure is under that of one atmosphere, or comprised between one and four atmospheres, or again if it be above four atmos-

pheres. Now when the steam is acting in an engine, it may happen, according to the load, or to other conditions of its motion, that the steam generated at first at a very high pressure, may act or be expanded in the engine sometimes at a pressure exceeding four atmospheres, sometimes at a pressure less than four atmospheres, but yet exceeding one, and sometimes at a pressure under that of one atmosphere. It is impossible then to know which of the three formulæ is to be used in the elimination; and consequently it is impossible by this means to attain a general formula representing the effects of the engine in all cases.

Moreover, were either one of these formulæ adopted, the high radical quantities they contain would so complicate the calculations as to render them unfit for practical purposes. And it is to be remarked, that these diverse formulæ, after all, are not the expression of the true mathematical law which connects the temperature and the pressure in saturated steam, but merely empirical relations, which experiment alone has demonstrated to have a greater or less degree of approximation.

A formula of temperatures given by M. Biot is indeed adapted to all points of the scale, and may be useful in a great number of delicate researches relative to the effects of steam; but as it gives only the pressure in terms of the temperature, and is, from its form, incapable of the inverse solution, namely, the general determination of temperatures in terms of the pressure, it is unfit for the elimination proposed.

Under these circumstances the only resourse is to seek a direct relation in terms of the pressure alone, whose results shall represent immediately those of the two preceding formulæ combined; that is, to calculate first by means of those formulæ a table of volumes of the steam, and then to seek a direct and simple relation to represent those results. This we have done.

M. Navier had proposed a formula for this purpose. But that formula, though sufficiently exact in high pressures, differs widely from experience in pressures below that of the

atmosphere, which are useful in condensing engines; and it is possible to find one much more exact for non-condensing engines, namely, that we are about to offer. We propose then, for this purpose, the following formulæ, in which p represents the pressure of the steam expressed in pounds per square foot, and μ the ratio of the volume of the steam to that occupied by the same weight of water:

Formula for high or low pressure engines *with condensation* $\quad \mu = \dfrac{10000}{0{\cdot}4227 + 0{\cdot}00258\,p}$

Formula for high pressure *non-condensing* engines $\quad \mu = \dfrac{10000}{1{\cdot}421 + 0{\cdot}0023\,p}$

The first formula is equally suitable to pressures above and below that of the atmosphere, at least within the limits likely to be considered in applying it to condensing steam-engines. Those limits are eight or ten atmospheres for the highest pressures; and eight or ten pounds per square inch for the lowest, in consequence of the friction of the engine, the pressure subsisting against the piston after imperfect condensation in the cylinder, and the resistance of the load. Within these limits then the proposed formula will be found to give very approximate results.

This first formula might also be applied, without any error worthy of notice, to non-condensing engines. But as, in these, the steam can scarcely operate with a pressure less than two atmospheres, by reason of the friction of the engine and the resistance of the load, it is needless to require of the formula exact results of volumes for pressures under two atmospheres.

In this case then the second formula will be found to give those results with much greater accuracy, and will consequently be preferred in practice. This will be readily recognised in a table annexed to the work, presenting a comparison of the volume of the steam calculated by the ordinary formulæ in terms of the pressure and temperature, and by the proposed formulæ in terms of the pressure alone.

We state then generally this analogy:

$$\mu = \frac{1}{n + q\,p} \ldots . (a)$$

Consequently, if the steam pass in the engine, from a certain volume m' to another known volume m, and thereby abandon its primitive pressure P', to assume an unknown pressure p, it is easy to recognise that the following relation will exist between those two pressures, and will serve to determine the unknown quantity p, viz.:

$$\frac{p}{P'} = \frac{m'}{\mu} \cdot \frac{1 - n\,\mu}{1 - n\,m'}.$$

This is the relation which we substitute in lieu of that hitherto employed, and according to which the volume appears to vary in the inverse ratio of the pressure. It will be observed that such an hypothesis may be deduced from the analogy we have just offered, by making $n = 0$, and $q = \frac{m\,P}{p}$, m being the volume, and P the pressure of the steam in the boiler; for it is plain that we shall then have,

$$\mu = \frac{m\,P}{p},$$

that is to say, the volumes are inversely as the pressures.

§ 2. *Of the divers problems which present themselves in the calculation of steam engines.*—We distinguish three cases in an engine: that wherein it works with a given rate of expansion of the steam, and with a load or a velocity indefinite; that in which it works with a given rate of expansion, and with the load and velocity proper to produce its maximum of useful effect with that expansion; and lastly that wherein, the engine having been previously regulated for the expansion of the steam most favourable in that engine, it bears, moreover, the load most advantageous for that expansion; which, consequently, produces the absolute maximum of useful effect in the engine.

We have said that the three fundamental problems of the calculation of steam engines consist in finding successively the velocity, the load, and the vaporization of the engine. After the solution of these three problems, that which first

presents itself, as a corollary to them, consists in determining the *useful effect* of the engine, which may be expressed under six different forms, viz.: by the work done, or the number of pounds raised one foot high by the engine in a minute; by the horse power of the engine; by the actual duty or useful effect of one pound of coal; by the useful effect of a cubic foot of water converted into steam; and by the number of pounds of coal, or of cubic feet of water, that are necessary to produce one horse power.

Another research, in fine, no less important, is the rate of expansion at which the steam must work in an engine, in order that it may produce given effects. We shall present successively the solution of all these questions.

The various problems will be resolved in each of the three cases above mentioned. In the last two, the question will be to calculate the rate of expansion, the velocity, the load, and the effects which correspond to the maximum of, relative or absolute, useful effect of the engine.

In the ordinary calculations of steam engines, the solution of three questions only had been attempted, viz.,—to find the load, the vaporization, and the useful effect, under its different forms; which solution is, as we have seen, faulty. As to the determining of the velocity for a given load, and that of the rate of expansion for given effects, the calculation of these had not been proposed. Moreover, the very nature of the theory employed in those calculations did not allow of distinguishing, in the machine, the existence of the three cases which are really found in it. The distinction we establish may, therefore, at first appear obscure, expressed, as it is, in general terms, and including relations unusual in the consideration of steam engines; but, on a closer view of the question, these relations will be seen to be of indispensable necessity, in order to calculate with exactitude either the effects or the proportions of steam engines of all systems.

§ 3. *Of the velocity of the piston under a given load.*—To embrace at once the most complete mode of action of the steam, we will suppose an engine working by expansion, by

condensation, and with an indefinite pressure in the boiler; and to pass on to unexpansive or uncondensing engines, it will suffice to make the proper suppressions or substitutions in the general equations.

From what has been already shown of our theory, the relations sought between the various data of the problem are necessarily deduced from two general conditions: the first expressing that the engine has attained a uniform motion, and consequently that the quantity of labour impressed by the motive power is equal to the quantity of action developed by the resistance: the second, that there is a necessary equality between the emission of steam through the cylinder and the production by the boiler.

The limits of this extract will not allow us to develop those calculations, simple as they may be; but that the proceeding may be understood, we shall state that, expressing by P the pressure of the steam in the boiler, and by P′ the pressure of the same steam in the cylinder before the expansion, by L the length of stroke of the piston, and by L′ the portion traversed at the moment the expansion begins, by a the area of the piston, and by c the clearance of the cylinder, or the space at each end of the cylinder beyond the portion traversed by the piston, and which necessarily fills with steam at each stroke; lastly, by r the resistance of the load, by p the pressure subsisting on the other side of the piston after imperfect condensation, by f the friction of the engine when not loaded, and by δ the increase of that friction per unit of the load r, these four forces, as well as the pressures, being moreover referred to the unit of surface of the piston; the first of the above conditions produces the following analogy:

$$\frac{\mathrm{P}' a\,(\mathrm{L}'+c)}{1-n\,a\,(\mathrm{L}'+c)}\left\{\frac{\mathrm{L}'}{\mathrm{L}'+c}+\log.\frac{\mathrm{L}+c}{\mathrm{L}'+c}-n a\,\mathrm{L}\right\}=$$
$$a\,\mathrm{L}\left((1+\delta)r+p+f\right)\;.\;.\;.\;.\;.\;(\mathrm{A})$$

This equation expressing that the labour developed by the mover is found entire in the effect produced, be it remarked, that it is not essentially necessary for the motion to be

strictly uniform. It may equally be composed of equal oscillations, beginning from no velocity, and returning to no velocity, provided the change of velocity take place by insensible degrees, so as to avoid the loss of *vis viva*, and that the successive oscillations be performed in equal times.

As to the second condition of the motion; if we denote by S the volume of water vaporized by the boiler in a unit of time and transmitted to the cylinder, by m the volume of the steam formed under the pressure P of the boiler, compared with the volume of the same weight of water unvaporized, and by v the velocity of the piston, the equality between the production of the steam and its consumption will be found to furnish the second general analogy:

$$\frac{S}{n + q P'} = \frac{v}{L} a \; (L' + c) \; . \; . \; . \; . \; (B)$$

Consequently, by eliminating P′ from these two equations, and writing, for greater simplicity,

$$\frac{\frac{L}{L' + c} - n a L}{\frac{L'}{L' + c} + \log. \frac{L + c}{L' + c} - n a L} = \varkappa,$$

we find definitively:

$$v = \frac{L}{L' + c} \cdot \frac{S}{a} \cdot \frac{1}{n + q \varkappa \left\{ (1 + \delta) r + p + f \right\}} \; . \; . \; (1)$$

an equation which gives the velocity of the motion in terms of the load and of the other data of the problem.

This formula is quite general, and suits every kind of steam engine with continued motion. If the engine be expansive, L′ will be replaced by its value corresponding to the point of the stroke where the steam begins to be intercepted; if the engine be unexpansive, it will suffice to make $L' = L$, which will give at the same time $\varkappa = 1$. If it be a condensing engine p must stand for the pressure of condensation; if it be not a condenser, p will represent the atmospheric pressure. And finally, the quantities n and q will have, according to the case considered, the above-mentioned value.

§ 4. *Of the load and useful effects of the engine.*—If, in-

stead of seeking the velocity in terms of the load it be required, on the contrary, to know the load suitable to a given velocity, the same equation resolved with reference to r becomes,

$$ar = \frac{\frac{L}{L' + c} S - n\,a\,v}{(1 + \delta)\,q\,v\,\varkappa} - a\,\frac{p + f}{1 + \delta} \quad \ldots \quad (2)$$

3°. To find the vaporization of which the engine ought to be capable, in order to put in motion a resistance r with a known velocity v, the value of S must be drawn from the same analogy, thus:

$$S = \frac{L' + c}{L}\,av\left(n + q\,\varkappa\left\{(1 + \delta)\,r + p + f\right\}\right) \quad \ldots \quad (3)$$

4°. The useful effect produced by the machine, in the unit of time, at the velocity v, is evidently arv. Hence that useful effect will have for its measure,

$$uE. = \frac{\frac{L}{L' + c} S - nav}{(1 + \delta)\,q\,\varkappa} - av\,\frac{p + f}{1 + \delta} \quad \ldots \quad (4)$$

5°. If it be desired to know the useful effect, in horse power, of which the engine is capable at the velocity v, or when loaded with the resistance r, it suffices to observe that what is called one horse power represents an effect of 33,000 ℔s. raised one foot per minute. All consists then in referring the useful effect produced by the engine in a unit of time, to the new unity just chosen, viz, to one horse power; and it will consequently suffice to divide the expression already obtained in the equation (4) by 33,000. Thus the useful effect in horse power will be,

$$uHP. = \frac{uE.}{33000} \quad \ldots \quad (5)$$

6°. We have just expressed, in the two preceding questions, the effect of the engine by the work which it is capable of performing. We are now on the contrary about to express that effect by the force which the engine expends to produce a given quantity of work. The useful effect of the equation (4) being that which is due to the volume of water S converted into steam, in the unit of time, if we suppose

that in the same unit of time N pounds of fuel be consumed, it is clear that the useful effect produced by each pound of fuel will be the Nth part of the above effect. It will then be,

$$\text{uE. 1 ℔. co.} = \frac{\text{uE.}}{\text{N}} \quad \ldots\ldots\ldots \quad (6)$$

To apply this formula, it will suffice to know the quantity of coal consumed in the furnace per minute, that is, during the production of the vaporization S; and this datum may be deduced from a direct experiment on the engine, or from known experiments on boilers of a similar construction.

7°. The useful effect of the equation (4) being that which proceeds from the vaporization of the volume of water S, if it be required to know the useful effect that will be produced by each cubic foot of water, or by each unit of S, it will be sufficient to divide the total effect uE. by the number of units in S. It will then be,

$$\text{uE. 1 ft. wa.} = \frac{\text{uE.}}{\text{S}} \quad \ldots\ldots \quad (7)$$

8°. In the sixth problem we have obtained the useful effect produced by one pound of fuel. We may then, by a simple proportion, deduce from thence the quantity of fuel necessary to produce one horse power, viz.

$$\text{Q. co. for 1 hp.} = \frac{33000\,\text{N}}{\text{uE.}} \quad \ldots\ldots \quad (8)$$

9°. And similarly, the quantity or volume of water necessary to produce one horse power will be,

$$\text{Q. wa. for 1 hp.} = \frac{33000\ \text{S}}{\text{uE.}} \quad \ldots\ldots \quad (9)$$

§ 5. *Of the expansion of steam, to be adopted in an expansive engine, in order to produce wanted effects.*

10° Finally, if it be required to know what rate of expansion the engine must work at, in order to obtain from it determined effects, the value of L′ must be drawn from equation (1.) It will be given by the formula,

$$\frac{L'}{L'+c} + \log.\frac{L+c}{L'+c} = q\,a\,L\left\{(1+\delta)r + p + f\right\}$$

$$\frac{\frac{v}{L} - nav\frac{L' + c}{L}}{S - nav\frac{L' + c}{L}} + naL \ldots . (10)$$

This formula not being of a direct application, we annex to the work a table which gives its solutions for the expansion from hundredth to hundredth, with a very short calculation.

We confine ourselves to these inquiries as being those which may most commonly be wanted; but it is clear that by means of the same general analogies, any one whatever of the other quantities which figure in the problem may be determined, as the case may require. Thus, for instance, may be determined the area of the piston, or the pressure in the boiler, or the pressure in the condenser, corresponding to determined effects of the machine, as has been done for locomotives in our work on that subject.

ART. II.

CASE OF THE MAXIMUM USEFUL EFFECT, WITH A GIVEN RATE OF EXPANSION.

§ 1. *Of the velocity of the maximum useful effect.* We have resolved the above problems in all their generality, that is, supposing the engine to move any load whatever with any velocity whatever, under this single condition, that the load and the velocity be compatible with the capability of the machine. The question is now to find what velocity and what load are most advantageous for the working of the engine, and what are the effects which, in this case, may be expected from it; that is to say, its maxima effects for a given rate of expansion.

1°. In examining the general expression of the useful effect produced by the engine at a given velocity, we perceive that the expression attains its maximum for a given rate of expansion when the velocity is a minimum; now

from the equation (B) the smallest value of v will be given by $P' = P$. The velocity corresponding to the maximum useful effect will therefore be,

$$v' = \frac{S}{a(n + qP)} \cdot \frac{L}{L' + c} \ldots (11)$$

Let us however remark, that, mathematically speaking, the pressure P' of the steam in the cylinder can never be quite equal to P, which is the pressure in the boiler; because there exist between the boiler and the cylinder conduits through which the steam has to pass, and the passage of these conduits offers a certain resistance to the motion of the steam: whence results that there must exist, on the side of the boiler, a trifling surplus of pressure equivalent to the overcoming of the obstacle. But as we have proved elsewhere, that, with the usual dimensions of engines, this difference of pressure is not appreciable by the instruments used to measure the pressure in the boiler, the introduction of it into the calculations would render the formulæ more complicated without making them more exact. For this reason we neglect that difference here.

The velocity given by the preceding equation is, then, that at which the engine will produce its maximum effect for a given expansion. This velocity will result from the condition $P' = P$, or reciprocally, when this velocity takes place in the engine, the steam enters the cylinder with full pressure, that is, with the same pressure it has in the boiler. It is necessary to remark that the velocity of full pressure will not be the same for all engines; on the contrary, it will vary in direct ratio with the vaporization, and in the inverse ratio of the area of the cylinder. It may then occur to be, in one engine, the half or the double of what it would be in another; which shows that it is an error to believe that, because the piston of stationary engines does not in general exceed a certain velocity of from 150 to 250 English feet per minute, the steam of the boiler necessarily reaches the cylinder with no change of pressure.

It is easy to be seen that a fixed limit, whatever it may be, cannot in this respect suit all engines; and that the only

means of knowing the velocity of the maximum effect, or of full pressure of an engine, is to calculate it directly for that engine. Such is the object of the formula we have just given. This formula, moreover, is of a remarkable simplicity, and requires no other experimental knowledge than that of the production of steam of which the boiler is capable.

§ 2. *Of the load and maximum useful effect of the engine.*—2°. The useful resistance which the machine is capable of putting in motion at its velocity of the maximum effect above, is to be drawn from equation (2,) substituting for v the value just obtained. Calling the load r' we shall find it expressed by

$$ar' = \frac{a\,P}{(1+\delta)\,\varkappa} - a\,\frac{p+f}{1+\delta}; \quad \ldots \, (12)$$

and it is at the same time visible that this load is the greatest the engine can put in motion with the given expansion L', for it corresponds to the lowest value of v in equation (2.) Thus the greatest effect of the machine, with a given rate of expansion, is attainable by working the machine at its smallest velocity and with its maximum load.

It will be observed, that this equation may be used to determine the friction of the engine without a load, and its additional friction per unit of the load, upon the same principles that we have employed in our Treatise of Locomotive Engines for similar determinations. This is also the mode we propose for steam-engines of every system.

3°. The vaporization necessary to an engine, in order to exert a certain maximum effort r' at its minimum velocity v' will be given by equation (3,) by substituting in it r' and v', or will be drawn more simply from equation (11,) thus:—

$$S = (n + q\,P)\,av'.\,\frac{L'+c}{L} \ldots \, (13)$$

4°. The maximum of useful effect producible in the unit of time, by an engine working with a given expansion, will

be known by formula (4,) by introducing for v the velocity proper to produce that effect. Thus is found,

$$\text{max. uE.} = \frac{L}{L'+c} \cdot \frac{S}{(1+\delta)(n+q\,P)} \left\{ \frac{P}{\varkappa} - (p+f) \right\} \ldots (14)$$

It will be observed that this maximum useful effect depends particularly on the quantity of water S, evaporated per minute in the boiler. Hence we see plainly the error of those who pretend to calculate the useful effect or the power of engines from the area and the velocity of the piston, which they set in the place of the vaporization produced; this vaporization not only entering not into their calculation, but forming no part of their observations.

5°. The useful effect, in horse power, of the engine will be expressed by

$$\text{uHP.} = \frac{\text{max. uE.}}{33000} \ldots\ldots (15)$$

6°. 7°. 8°. 9°. The various measures of the useful effect will here be deduced from equations similar to those (6,) (7,) (8,) and (9.)

10°. The expansion at which the engine ought to be regulated, in order to draw a given load at the most advantageous velocity, or producing the maximum of useful effect with that load, will be derived from equation (12,) which gives,

$$\frac{L'+c}{L} \left\{ \frac{L'}{L'+c} + \log. \frac{L+c}{L'+c} \right\} = \frac{(1+\delta)r + p + f}{P} + na\frac{L'+c}{L} \left\{ L - L\frac{(1+\delta)\,r' + p + f}{P} \right\} \ldots\ldots (20)$$

and the solutions of this formula will be found immediately, and without calculation, by means of the table given above, as suggested by equation (10.)

ART III.

CASE OF THE ABSOLUTE MAXIMUM OF USEFUL EFFECT.

The preceding inquiries suffice for engines working without expansion, merely by making $L' = L$; because those

engines fall under the case of expansion fixed *à priori.* But it is otherwise with engines in which the rate of expansion may be varied at will. We have seen that, for a given expansion, the most advantageous way of working the engine is to give it the maximum load, which is calculated *à priori* from equation (12.) Hence we know what load is to be preferred for every rate of expansion. But the question now is to determine, among the various rates of expansion of which the engine is susceptible, each accompanied by its corresponding load, which will produce the greatest useful effect.

For this purpose we must recur to equation (14,) which gives the useful effect produced with a maximum load r', and seek among all the values assignable to L', that which will raise the useful effect to a maximum. Now by making the differential coefficient of that expression, taken with reference to L' equal to nothing, we find as the condition of the maximum sought:

$$\frac{\mathrm{L}'}{\mathrm{L}}=\frac{p+f}{\mathrm{P}}+na\,\mathrm{L}\frac{\log.\frac{\mathrm{L}+c}{\mathrm{L}'+c}-na\,\mathrm{L}\left(1-\frac{\mathrm{L}'}{\mathrm{L}}\right)}{\left(\frac{\mathrm{L}}{\mathrm{L}'+c}-na\,\mathrm{L}\right)^2}\quad\ldots\ldots(30)$$

This equation will be resolved in the same manner as the equations (10) and (20,) by means of the table already given; and after having found the value of $\frac{\mathrm{L}'}{\mathrm{L}}$, it will be introduced in the equations of article II.; and the corresponding velocity, load, and useful effects, will be determined.

However, as the supposition of $n = o$, $q = \frac{1}{m\mathrm{P}}$, that is to say, the supposition that the steam preserves its temperature during its action in the engine, will give a sufficient approximation in a great many cases, we present here the corresponding results of all the formulæ. They will show, already to a very near degree, the maximum absolute effects which it is possible to obtain from an engine

in adopting simultaneously the most advantageous rate of expansion and the most advantageous load.

$$(21)\ v'' = \frac{m\,S}{a} \cdot \frac{L\,P}{L(p+f)+Pc}$$ Velocity of the absolute maximum useful effect.

$$(22)\ ar'' = a\,\frac{L\,(p+f)+P\,c}{(1+\delta)\,L}\ \log.\frac{(L+c)\,P}{L\,(p+f)+P\,c}$$ Load of the piston corresponding to the absolute maximum useful effect.

$$(23)\ S = \frac{av''}{m} \cdot \frac{L\,(p+f)+P\,c}{L\,P}$$ Vaporization.

$$(24)\ {}^{\text{ab.max.u.}}E = ar''v'' = \frac{m\,S\,P}{1+\delta}\ \log.\frac{P\,(L+c)}{L\,(p+f)+P\,c}$$ Absolute maximum of useful effect.

$$(25)\ {}^{\text{u.}}HP = \frac{{}^{\text{ab.max.u.}}E}{33000}$$ Absolute maximum of useful force in horse power.

$$(30)\ L' = \frac{L\,(p+f)}{P}$$ Rate of expansion which produces these effects.

The four determinations of the useful effects of a given quantity of fuel or water will be furnished by equations similar to those (6,) (7,) (8,) and (9.)

The only remark we shall make on the subject of these formulæ is, that the load suitable to the producing of the absolute maximum useful effect is not the maximum load that may be imposed on the engine. In effect, from equation (12,) we know that the maximum load for the engine takes place when $L' = L$, and not when

$$L' = L\,\frac{p+f}{P}.$$

Thus the greatest possible load of the engine is that of the maximum useful effect without expansion; but by applying a lighter load, that of equation (22,) and at the same time the expansion of equation (30,) a still greater useful effect will be obtained.

PART III.

APPLICATION OF THE FORMULÆ TO THE VARIOUS SYSTEMS OF STEAM-ENGINES.

We shall not give here the applications to different systems of steam-engines, which are developed in this part of the work. We shall confine ourselves to what concerns Watt's steam-engines, because they are the most generally employed in the arts.

Watt's rotative double-acting steam-engine.—These engines being without expansion, the proper formulæ for calculating their effects will be deduced from the general formulæ by making $L' = L$, which will give also $x = 1$, and by replacing the quantity p by the pressure of condensation. We see, moreover, that for these engines, the expansion being susceptible of no variation, since that detent does not exist, the third case, considered as to engines in general, cannot occur. There will be then but two circumstances to consider in their working, viz., the case wherein they operate *with their maximum load, or load of greatest useful effect,* and the case in which they operate *with any load whatever.* The effects therefore of these engines will visibly be determined by the following equations:

General case, or of indefinite load.	*Case of maximum useful effect.*
$v = \frac{L}{L+c} \cdot \frac{S}{a} \cdot \frac{1}{n+q\left\{(1+\delta)r+p+f\right\}}$	$v' = \frac{L}{L+c} \cdot \frac{S}{a(n+qP)}$,
$ar = \frac{L}{L+c} \cdot \frac{S}{q(1+\delta)v} - \frac{a}{1+\delta}\left(\frac{n}{q}+p+f\right)$	$ar' = \frac{a}{1+\delta}(P-p-f)$
$S = \frac{L+c}{L} \cdot av\left[n+q\left\{(1+\delta)r+p+f\right\}\right]$	$S = \frac{L+c}{L} \cdot av'(n+qP)$
${}^{u.}E = arv = \frac{L}{L+c} \cdot \frac{S}{q(1+\delta)} - \frac{av}{1+\delta}\left(\frac{n}{q}+p+f\right)$	${}^{max.\,u.}E = ar'v' = \frac{L}{L+c} \cdot \frac{S}{(1+\delta)(n+qP)}\left\{P-p-f\right\}$

${}^{u.}HP = \frac{{}^{u.}E}{33000}$	${}^{u.}HP = \frac{max.\,u.\,E}{33000}$,
${}^{u.}E_{1\,lb.\,co.} = \frac{{}^{u.}E}{N}$	${}^{u.}E_{1\,lb.\,co.} = \frac{max.\,u.\,E}{N}$,
${}^{u.}E_{1\,ft.\,wa.} = \frac{{}^{u.}E}{S}$	${}^{u.}E_{1\,ft.\,wa.} = \frac{max.\,u.\,E}{S}$,
$Q_{co.\,for\,1\,hp.} = \frac{33000\,N}{{}^{u.}E}$	$Q_{co.\,for\,1\,hp.} = \frac{33000\,N}{max.\,u.\,E}$,
$Q_{wa.\,for\,1\,hp.} = \frac{33000\,S}{{}^{u.}E}$	$Q_{wa.\,for\,1\,hp.} = \frac{33000\,S}{max.\,u.\,E}$.

Although these formulæ may at first sight appear complicated, they will nevertheless be found very simple in the calculation. It is only necessary to fix attention to refer all the measures to the same unit, as will be seen in the following example. It must be remarked also, that as soon as the velocity and load of the engine are determined, the useful effect will be known immediately, being their produce.

To apply, however, these formulæ, some previous observations are necessary.

In good engines of that system the pressure in the condenser is usually 1·5 ℔. per square inch, but the pressure in the cylinder itself, and under the piston, is in general 2·5 ℔s. more, which gives $p = 4 \times 144$ ℔s. It has been deduced, moreover, from a great number of trials made on Watt's engines, that their friction, when working with a moderate load, varies from 2·5 ℔s. per square inch of the piston, in engines of smaller dimensions; to 1·5 ℔. in the more powerful ones; which includes the friction of the parts of the machinery and the force necessary for the action of the feeding and discharging pumps, &c. By moderate load in these engines is meant about 8 ℔s. per square inch of the piston. Now our experiments on locomotives, showing the *additional* friction of an engine to be $\frac{1}{8}$ of the resistance, give room to think, that the *additional* friction caused in the engine by that load may be about 1 ℔. per square inch. The above information attributes then to Watt's engines, working unloaded, a friction of from 1·5 ℔. to ·5 ℔. per square inch, according to their dimensions, which would give 1 ℔. for engines of a medium size: this information, agreeing with what we have deduced from our inquiries on locomotives, as has been said above, we shall continue to admit, in this place, respecting the friction, the data already indicated in this respect, viz.:—

$$f = 1 \times 144 \text{ ℔s.} \qquad \delta = \cdot 14.$$

As an application of these formulæ, we will submit to calculation an engine constructed by Watt at the *Albion Mills* near London. The following were its dimensions:—

Diameter of the cylinder, 34 inches, or $a = 6{\cdot}287$ square feet;

Stroke of the piston, 8 feet, or $L = 8$ feet;

Clearance of the cylinder, $\frac{1}{20}$ of the stroke, or $c = {\cdot}4$ foot;

Effective vaporization, ·927 cubic foot of water per minute, or $S = {\cdot}927$ cubic foot;

Consumption of coal in the same time, 6·71 ℔s., or $N = 6{\cdot}71$ ℔s.;

Pressure in the boiler, 16·5 ℔s. per square inch, or $P = 16{\cdot}5 \times 144$ ℔s.;

Mean pressure of condensation, 4 ℔s. per square inch, or $p = 4 \times 144$ ℔s.

And finally, the engine being a condensing one, we have $n = {\cdot}4227$ and $q = {\cdot}000000258$.

The engine had been constructed to work at the velocity of 256 feet per minute, which was considered its normal velocity; but when put to trial by Watt himself, shortly after its construction, it assumed, in performing its regular work, esteemed 50 horse-power, the velocity of 286 feet per minute, consuming at the same time the quantity of water and fuel which we have just reported.

If then we seek the effects it was capable of producing at its velocity of maximum effect, and then at those of 256 and 286 feet per minute, we shall find, by the formulæ already exposed:

Maximum useful effect.

v	=	286	256	$v' =$ 214	Velocity of the piston in feet per minute;
ar	=	5,621	6,850	9,133	Total load of the piston in ℔s.;
$\frac{r}{144}$	=	6·21	7·57	10·09	Load of the piston in ℔s. per square in.;

S	=	·927	·927	·927	Vaporization in cubic feet of water per minute;
$\alpha \cdot E$	=	1,607,610	1,753,600	1,957,180	Useful effect in lbs. raised to one foot per minute.
$\alpha \cdot HP$	=	49	53	59	Useful effect in horse power.
$\alpha \cdot E^{1\ \mathrm{lb.\ co.}}$	=	239,585	261,340	291,680	Useful effect of 1 lb. of coal, in lbs. raised to one foot per minute.
$\alpha \cdot E^{1\ \mathrm{p.\ e.}}$	=	1,734,200	1,891,700	2,111,300	Useful effect due to the vaporization of one cubic foot of water, in lbs. raised to one foot per minute.
$Q^{\mathrm{co.\ for\ 1\ h.}}$	=	·138	·126	·113	Quantity of coal in lbs., producing the effect of one horse power.
$Q^{\mathrm{wa.\ for\ 1\ h.}}$	=	·019	·017	·016	Quantity of water, in cubic feet, producing the effect of one horse power.

Such are the effects that this engine should produce, and we see, in consequence, that in performing a labour estimated at fifty horses, it was to be expected the engine would acquire the velocity which in fact it did, viz., that of 286 feet per minute.

Let us now see to what results we should have been led, had we applied the ordinary calculations to the experiment of Watt, which we have just reported. In this experiment, the engine vaporizing ·927 cubic foot of water, and exerting the force of fifty horses, assumed a velocity of 286 feet per minute.

We then find that, since the engine had a useful effect of no more than fifty horses, and that the theoretical force, calculated according to that method, from the area of the cylinder, the effective pressure in the boiler, and the velocity of the piston, was,

$$\frac{6{\cdot}287 \times (16{\cdot}5 - 4) \times 144 \times 286}{33000} = 98 \text{ horses.}$$

It resulted that, to pass from the theoretical effects to the practical, it was necessary to use the coefficient ·51. Consequently, by following the reasonings of that theory, the following conclusions were to be drawn:—

1°. The observed velocity being 286 feet per minute, the vaporization calculated on the quantity of water, which reduced to steam at the pressure of the boiler, might occupy the volume described by the piston, and afterwards divided, as is done, by the coefficient, to take the losses into account, would have been:

$$\frac{\frac{1}{1530} \times 6{\cdot}287 \times 286}{{\cdot}51} = 2{\cdot}305$$ cubic feet per minute, instead of ·927.

2°. The engine having vaporized only ·927 cubic foot of water per minute, the velocity calculated on the volume of steam formed, at the pressure of the boiler, and afterwards reduced by the coefficient, not as has been done, since this problem was not resolved, but as must naturally be con-

cluded from the signification attributed to that coefficient, could but be

$$\frac{1530 \times \cdot 927}{6 \cdot 287} \times \cdot 51 = 115 \text{ per minute, instead of } 286.$$

3°. The coefficient found by the comparison of the theoretical effects to the practical being ·51, the various frictions, losses, and resistances of the engine would amount to ·49 of the effective power; whereas these frictions, losses, and resistances, consisting merely of the friction of the engine and the clearance of the cylinder, could be estimated only as follows:—

Total friction (including the additional friction) 2 lbs. per square inch, or as a fraction of the effectual pressure, $\frac{2}{12}$	·17
Clearance of the cylinder, $\frac{1}{20}$ of the effective force, or	·05
	·22

Some authors also employ constant coefficients, not however using the same to determine the vaporization as to find the useful effect. This manner of calculating has arisen from those authors having recognised from experience, that the steam has in the cylinder a less pressure and density than in the boiler; but as they cannot settle *à priori* what is that pressure in the cylinder, and that they always seek to deduce it from that of the boiler, instead of concluding it directly and in principle, from the resistance on the piston, as we do; the diminution of pressure observed by them could not be defined in its limits, and it remained simply a practical fact which they used to explain the coefficient. This change in the coefficient employed, avoids the first and second of the contradictions we have just indicated; but the third, as well as all the objections we have developed in the first part against the use of any constant coefficient, remain in full force; that is to say, that in this method, the power of the engine is calculated independently of the vaporizing force of the boiler, and the vaporization

independently of the resistance to be moved; that the effort exerted by the machine is found always the same at all velocities; that no account can be taken of the opening of the regulator, unless a new series of coefficients be introduced to that end, as well as for all the changes of velocity, &c.

In consequence, we conclude from this comparison, as well as from what precedes, that the theory in general use for calculating the effects or the proportions of steam engines, cannot lead to any sure results; while the one, which we have deducted from the best known principles in mechanics, and from the direct observation of what takes place in the engines, represents their effects with accuracy.

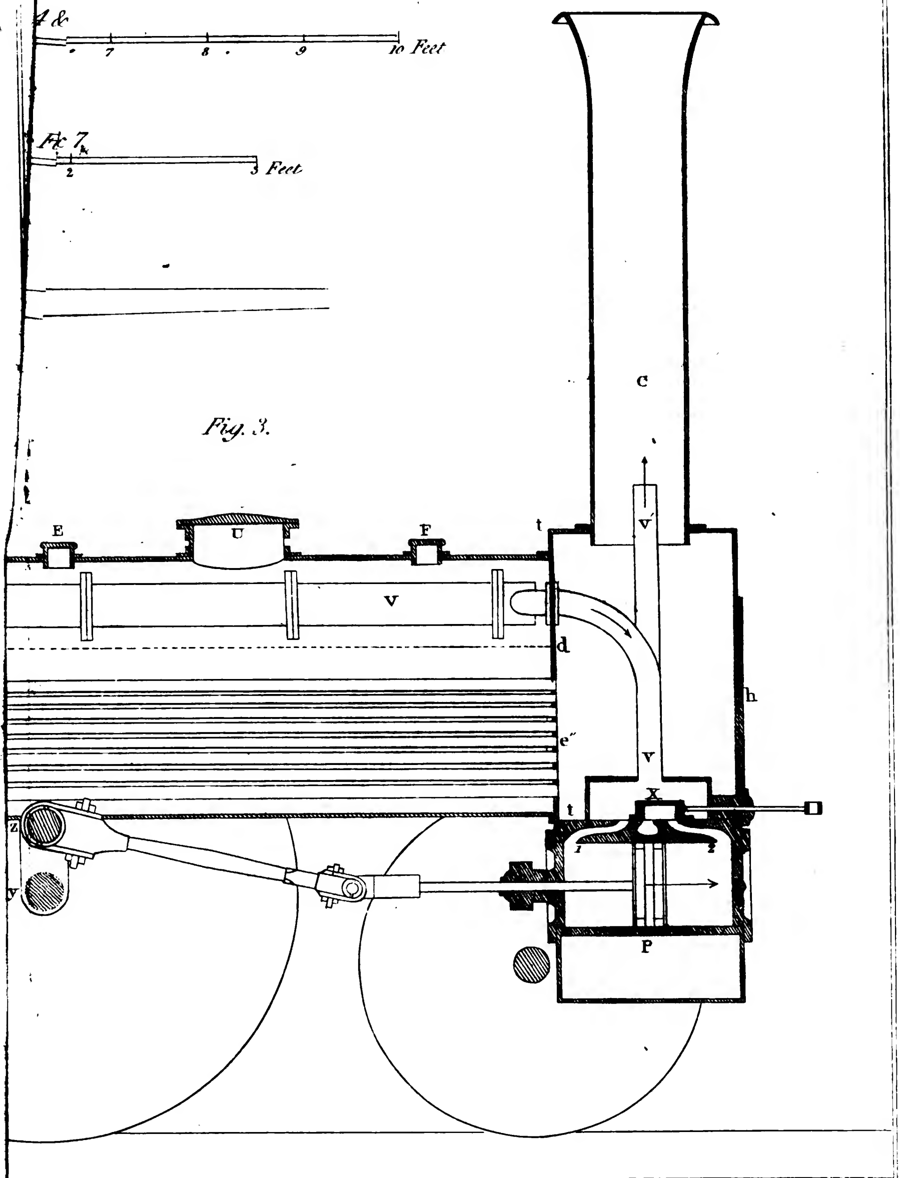


Fig. 3.

Fig. 8.

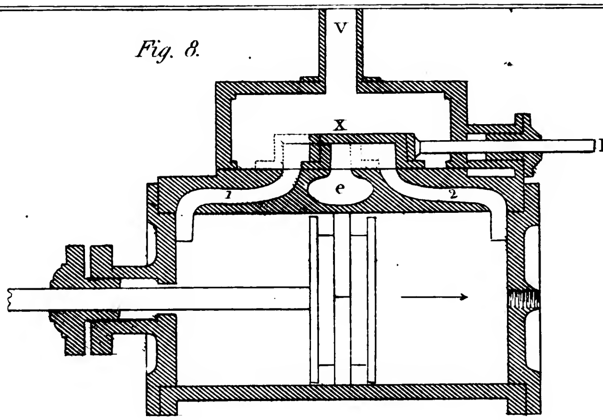


Fig. 27.

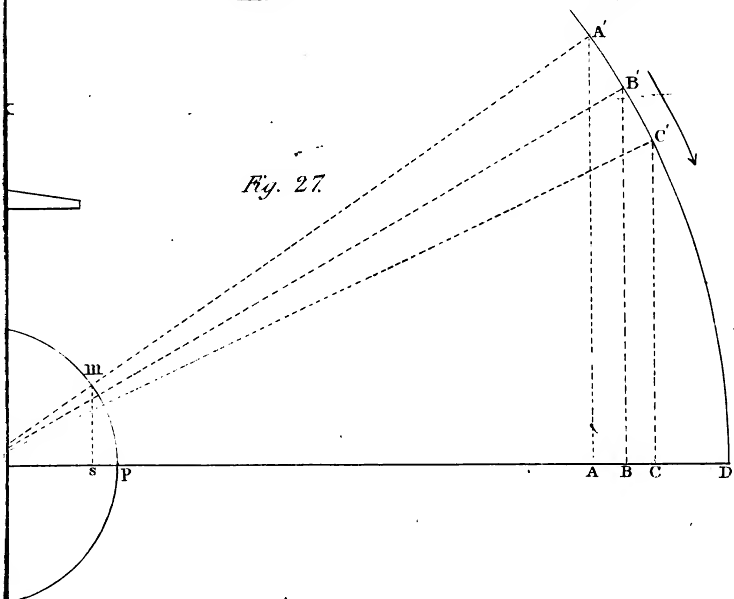
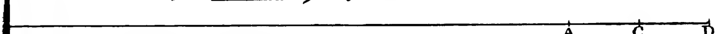
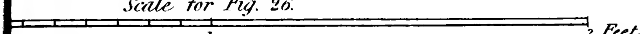


Fig. 25.



Scale for Fig. 26.



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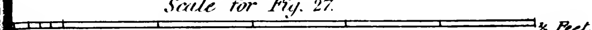

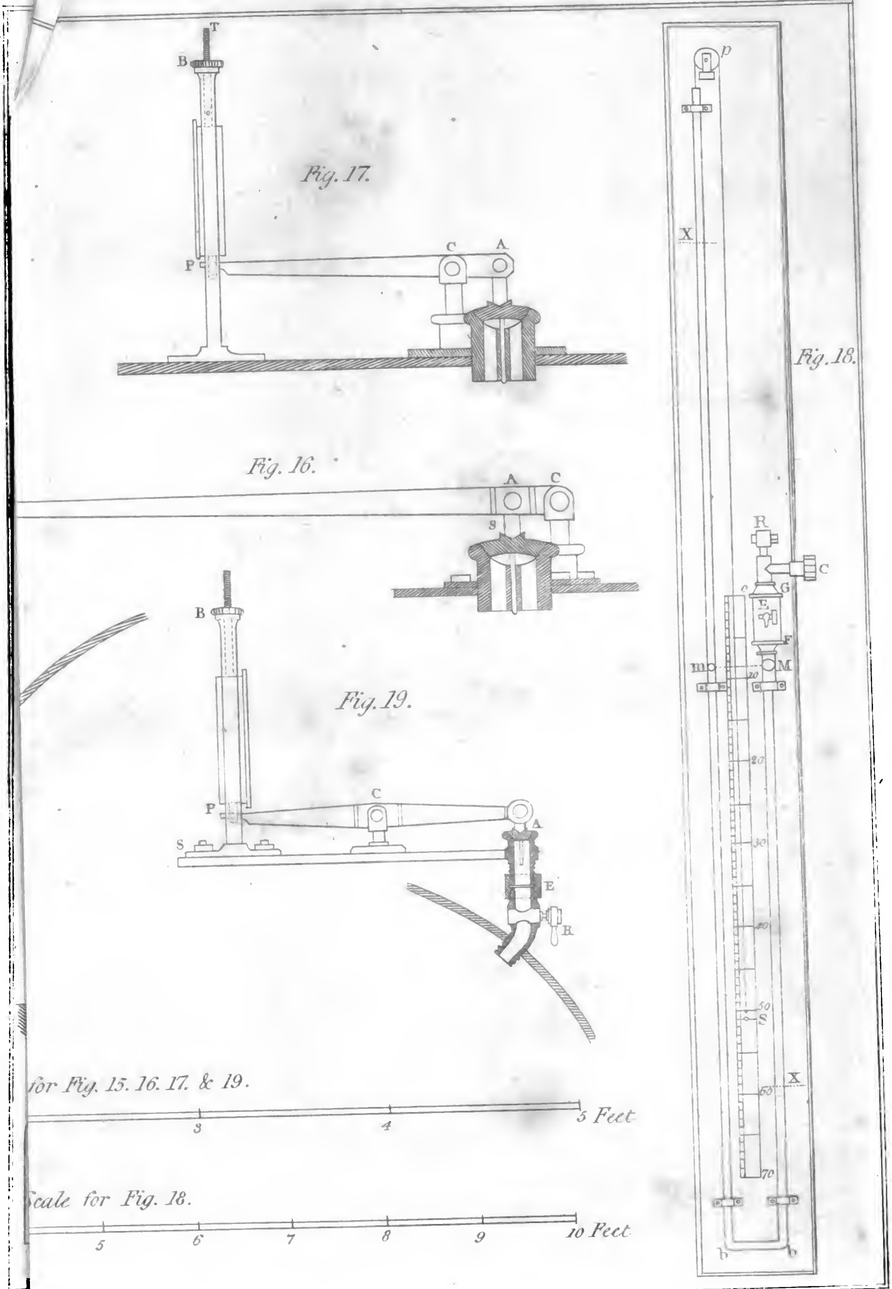
Fig. 17.
Fig. 16.
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Fig. 18.
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